Digitized by Illinois College of Optometry Library

4⁰⁰

CHICAGO MEDICAL BOOK CO.
CONGRESS & HONORE STS.
CHICAGO

Digitized by Illinois College of Optometry Library

E. W. Kleiner
707 W North Ave

ILLINOIS COLLEGE OPTOMETRY
LUX ET VERITAS

Carl F. Shepard Memorial Library

Donated by: E. W. Kleiner, O.D.

Digitized by Illinois College of Optometry Library

Digitized by Illinois College of Optometry Library

THE PRACTICE OF REFRACTION

BY

W. STEWART DUKE-ELDER

M.A., D.Sc.(St. And.), Ph.D.(Lond.), M.D., Ch.B., F.R.C.S.

Assistant Ophthalmic Surgeon, St. George's Hospital; Assistant Surgeon, Royal London Ophthalmic (Moorfields) Hospital; Assistant Lecturer in Ophthalmology, St. George's Hospital Medical School, University of London

WITH 208 *ILLUSTRATIONS*

PHILADELPHIA

P. BLAKISTON'S SON & CO. INC.

1012 WALNUT STREET

1928

Digitized by Illinois College of Optometry Library

Carl F. Shepard Memorial Library
Illinois College of Optometry
3241 S. Michigan Ave.
Chicago, Ill. 60616

Illinois College of Optometry
3241 S. Michigan Ave.
Chicago, Ill. 60616

Digitized by Illinois College of Optometry Library

Printed in Great Britain

PREFACE

The purpose of this book is to present in a manner suitable for the student and the practitioner the essential principles of the theory and practice of the correction of defects in the optical system of the eyes and their associated muscles. A simple and essentially non-mathematical form of presentation has therefore been adopted, wherein all that is necessary for the clinical practice of refraction is described and explained without burdening the reader with innumerable mathematical proofs. The book is thus clinical rather than theoretical, and its object is essentially practical; and, while theoretical matters are dealt with sufficiently to make their application to practical problems understandable, no attempt has been made to enter into the mathematical foundations of the subject.

It may be argued—and with perfect reason—that such a course is unjustifiable; that optics without mathematics is a science without a soul; and that no one should avail himself of the applications of optics who is not conversant with the fundamental principles involved. But, on the other hand, most of these principles can be understood and appreciated in non-mathematical terms, and many who would practise the application of these principles, and whose training has been essentially biological and clinical, have neither the aptitude nor the inclination to appreciate the true significance of a mathematical formulation. In any case, at the present time a mathematical presentation of the subject would be superfluous. For those who wish to enter deeply into the subject no better treatise could be desired than Helmholtz's "Physiological Optics," now brought up to date and translated into English by the Optical Society

Digitized by Illinois College of Optometry Library

ILLINOIS COLLEGE OF OPTOMETRY

of America (1924–25); those who wish the essentials of the theory of refraction presented more compactly are referred to Goulden's "Refraction of the Eye" (Churchill, 1925); while the mathematical problems involved in the theory of spectacles will be found in Percival's "Prescribing of Spectacles" (Wright & Sons, 1928), from which I have quoted largely.

But whatever the type of book the would-be refractionist uses, it cannot be insisted upon too strongly that the art of refraction cannot in any sense be learned by reading. There is only one way of attaining efficiency therein, and that is by assiduous and painstaking practice in the clinic of a hospital, where large numbers of cases of all kinds are available, where the findings can be supervised and corroborated, and where long practice makes the interpretation of results instantaneous. If these pages serve as a guide in this they will have achieved their aim.

In the preparation of this book I have to express my indebtedness to Messrs. Theodore Hamblin, who were responsible for the great majority of the illustrations. In the execution of these they have spared no pains and voluntarily spent a large amount of time and trouble. I am indebted also to my teacher, Sir John Parsons, for a considerable number of illustrations from his "Diseases of the Eye," to Mr. Goulden for a similar courtesy from his "Refraction of the Eye," and to Mr. Neame and Mr. Williamson-Noble from their "Handbook of Ophthalmology." Mr. E. E. Henderson and Mr. R. R. James have again earned my thanks by their kindness in reading over the proofs, and by their greater kindness in supplying me with advice and criticism. Finally, Messrs. J. & A. Churchill have once more proved to me how pleasant and helpful may be the relations between an author and his publishers.

W. S. DUKE-ELDER.

Harley Street, London, W.

Digitized by Illinois College of Optometry Library

CONTENTS

SECTION I
INTRODUCTORY

CHAPTER I
VISION

PAGE

THE EVOLUTION AND IMPORTANCE OF VISION . . 1

CHAPTER II
EYE-STRAIN

THE INCIDENCE OF EYE-STRAIN 4

THE SYMPTOMATOLOGY OF REFRACTIVE ERRORS . 6

The Symptoms of Gross Refractive Errors 6

The Symptoms of Small Refractive Errors 7

The mechanism of symptoms; the incidence of symptoms; visual symptoms; ocular symptoms; referred symptoms.

THE TREATMENT OF REFRACTIVE ERRORS . . . 16

Optical treatment; general treatment.

SECTION II
REFRACTION

CHAPTER III
THE PRINCIPLES OF REFRACTION

THE NATURE OF REFRACTION 21

REFRACTION BY A PLATE WITH PARALLEL SIDES . 23

REFRACTION BY PRISMS 26

The detection and measurement of prisms; the nomenclature of prisms.

REFRACTION BY LENSES 31

The nature of lenses; refraction by spherical lenses; refraction by cylindrical lenses; refraction by astigmatic lenses; the notation of lenses; the notation of cylinders; the detection and measurement of lenses.

REFRACTION BY OPTICAL SYSTEMS 51

Digitized by Illinois College of Optometry Library

CHAPTER IV

THE REFRACTION OF THE EYE

PAGE

THE REFRACTIVE SYSTEM OF THE EYE 55

Refraction at the corneal surface; refraction by the lens; the reduced eye.

THE OPTICAL DEFECTS OF THE EYE 63

PHYSIOLOGICAL OPTICAL DEFECTS 64

Diffraction of light; chromatic aberration; chromatic difference of magnification; spherical aberration; decentring; peripheral aberrations; circles of diffusion.

PATHOLOGICAL OPTICAL DEFECTS 72

Varieties of ametropia.

THE SIZE OF THE PUPIL; STENOPÆIC APERTURES 76

CHAPTER V

ANOMALIES OF REFRACTION

1. Hypermetropia

ÆTIOLOGY 79

OPTICAL CONDITION 82

The accommodation in hypermetropia.

THE NORMAL AGE VARIATION 85

CLINICAL PATHOLOGY 86

CLINICAL SYMPTOMS 89

TREATMENT 91

CHAPTER VI

ANOMALIES OF REFRACTION

2. Myopia

ÆTIOLOGY 98

Progress of myopia; clinical types of myopia.

CLINICAL PATHOLOGY 105

OPTICAL CONDITION 109

CLINICAL SYMPTOMS 110

PROGNOSIS 112

PROPHYLAXIS 112

TREATMENT 114

Digitized by Illinois College of Optometry Library

CHAPTER VII

ANOMALIES OF REFRACTION

3. Astigmatism

PAGE

ÆTIOLOGY 119

OPTICAL CONDITION 121

TYPES OF ASTIGMATISM 122

REGULAR ASTIGMATISM 124

Symptoms ; treatment.

OBLIQUE ASTIGMATISM 130

IRREGULAR ASTIGMATISM 133

Varieties ; symptoms ; treatment.

CHAPTER VIII

ANOMALIES OF REFRACTION

4. Anisometropia

THE VISION IN ANISOMETROPIA 138

THE TREATMENT OF ANISOMETROPIA 140

CHAPTER IX

ANOMALIES OF REFRACTION

5. Aphakia

DIAGNOSIS ; OPTICAL CONDITION ; TREATMENT . . . 145

CHAPTER X

CHANGES IN REFRACTION

PHYSIOLOGICAL CHANGES 149

PATHOLOGICAL CHANGES 150

Dynamic changes ; changes in glaucoma ; in trauma ; with pressure ; in inflammatory diseases ; in constitutional disease ; in diabetes.

Digitized by Illinois College of Optometry Library

SECTION III

ACCOMMODATION AND CONVERGENCE

CHAPTER XI

ACCOMMODATION

PAGE
THE NATURE OF ACCOMMODATION 155
THE MECHANISM OF ACCOMMODATION 156
PHYSICAL AND PHYSIOLOGICAL ACCOMMODATION . . 159
THE RANGE AND AMPLITUDE OF ACCOMMODATION . 160
THE MEASUREMENT OF THE ACCOMMODATION . . 161
ACCOMMODATION IN VARIOUS REFRACTIVE CONDITIONS 162
In emmetropia; in hypermetropia; in myopa; in astigmatism; in anisometropia.
THE AVAILABILITY OF ACCOMMODATION. . . . 166
PHENOMENA ASSOCIATED WITH ACCOMMODATION . 167

CHAPTER XII

CONVERGENCE

THE NATURE OF CONVERGENCE 168
THE MEASUREMENT OF CONVERGENCE 169
THE RELATION BETWEEN ACCOMMODATION AND CONVERGENCE 173
BINOCULAR ACCOMMODATION 177

CHAPTER XIII

PRESBYOPIA

THE NATURE OF PRESBYOPIA 179
THE VARIATION OF ACCOMMODATION WITH AGE . . 180
SYMPTOMS 182
TREATMENT 183

CHAPTER XIV

ANOMALIES OF ACCOMMODATION

VARIETIES OF ANOMALIES 187
THE NORMAL RANGE OF ACCOMMODATION . . . 188
EXCESSIVE ACCOMMODATION 189

Digitized by Illinois College of Optometry Library

	PAGE
SPASM OF ACCOMMODATION	191
INSUFFICIENCY OF ACCOMMODATION	192
ILL-SUSTAINED ACCOMMODATION	195
UNEQUAL ACCOMMODATION	196
PARALYSIS OF ACCOMMODATION	196
CYCLOPLEGIA	198

SECTION IV

THE MUSCLE BALANCE

CHAPTER XV

ORTHOPHORIA

THE NATURE OF ORTHOPHORIA	206
BINOCULAR VISION	207
THE FUSION FACULTY	209

CHAPTER XVI

HETEROPHORIA

THE NATURE OF HETEROPHORIA Causes; detection; varieties.	214
EXOPHORIA	218
ESOPHORIA	220
HYPERPHORIA	220
CYCLOPHORIA	221
SYMPTOMS	222
TREATMENT	223

CHAPTER XVII

HETEROTROPIA

THE NATURE OF HETEROTROPIA	230
PARALYTIC STRABISMUS Symptoms; diagnosis; treatment.	231
CONCOMITANT STRABISMUS Ætiology; the vision in concomitant strabismus; varieties; treatment.	236

Digitized by Illinois College of Optometry Library

SECTION V

CLINICAL METHODS

CHAPTER XVIII

OPHTHALMOLOGICAL EXAMINATION

PAGE

GENERAL OUTLINE OF OPHTHALMOLOGICAL EXAMINATION 251

CHAPTER XIX

VISUAL ACUITY

THEORY OF DETERMINATION 255

ROUTINE TESTING OF THE VISUAL ACUITY FOR DISTANT VISION 260

ROUTINE TESTING OF VISUAL ACUITY FOR NEAR VISION . 268

CHAPTER XX

OPHTHALMOSCOPIC EXAMINATION

IMPORTANCE OF OPHTHALMOSCOPIC EXAMINATION . 270

PRELIMINARY EXAMINATION WITH THE PLANE MIRROR 273

INDIRECT OPHTHALMOSCOPY 277

DIRECT OPHTHALMOSCOPY 283

CHAPTER XXI

RETINOSCOPY

OPTICAL CONDITIONS 286

THE THEORY OF RETINOSCOPY 287

THE PRACTICE OF RETINOSCOPY 293

Difficulties in refraction; cycloplegia.

THE OPHTHALMOMETER 303

CHAPTER XXII

SUBJECTIVE VERIFICATION OF THE REFRACTION, AND THE TESTING OF THE MUSCULAR EQUILIBRIUM

THE DISTANT VISION 305

The ordering of glasses for distance.

THE DETERMINATION OF THE ACCOMMODATION AND THE TESTS FOR NEAR VISION 312

The determination of glasses for near work.

Digitized by Illinois College of Optometry Library

PAGE

THE DETERMINATION OF THE MUSCLE BALANCE . 317

The investigation of heterophoria; of heterotropia.

SUMMARY OF CLINICAL METHODS 329

SECTION VI

SPECTACLES

CHAPTER XXIII

THE MAKING AND FITTING OF SPECTACLES

IMPORTANCE OF THE SUBJECT 332

THE MANUFACTURE OF GLASSES 333

Historical; spectacle lenses; spectacle frames; combinations of glasses.

SPECTACLE LENSES 345

The size and shape of lenses; the form of lenses; the transposition of lenses; the centring and decentring of lenses; orthoscopic lenses.

DISCOMFORTS ARISING THROUGH GLASSES 363

SPECIAL TYPES OF GLASSES 372

Protective glasses; special glasses for optical purposes.

APPENDICES

I. REFRACTIVE INDICES 383

II. TABLE SHOWING THE EQUIVALENTS OF CENTRADS IN PRISM DIOPTRES, IN DEGREES OF DEVIATION AND IN DEGREES OF REFRACTING ANGLE . . 384

RELATIONSHIP BETWEEN REFRACTING ANGLE OF PRISMS AND THE AMOUNT OF DEVIATION PRODUCED 384

III. METRE ANGLES 385

IV. LENSES OF SAME EFFECTIVITY FOR NEAR AND FOR DISTANT WORK 386

V. FORMULÆ FOR PERISCOPIC LENSES 387

VI. OFFICIAL VISUAL REQUIREMENTS 389

INDEX 402

Digitized by Illinois College of Optometry Library

Digitized by Illinois College of Optometry Library

THE PRACTICE OF REFRACTION

SECTION I

INTRODUCTORY

CHAPTER I

VISION

The response of living organisms to light dates from the earliest stages in the story of the evolution both of the vegetable and the animal world. In its most fundamental stages it is evident that the reaction evoked by the light is not primarily its appreciation as vision, but rather the more primitive response of movement. The phenomena of heliotropism in plants are well-known, and similar movements are common among the lowest animals; thus paramœcia, hydra, and fresh water polyps travel towards the light, the amœba and worms avoid it, some rhizopods and infusoria contract under its influence, shell-fish close their valves, and ascidians retract their syphons. It is true that in these early forms a primitive sensory impression appears to be conveyed, but this is apparently vague and undifferentiated, and is evidently limited to a sense of awareness of the existence of the light and an appreciation merely of its pleasantness or unpleasantness. Indeed, there is no evidence that vision, as we understand it, exists until amphibia are reached in evolutionary history.

In the earliest unicellular organisms the whole animal appears to respond to the stimulus of light; later the surface layer—eventually the epithelium—forms the receptor appa-

Digitized by Illinois College of Optometry Library

ratus; and at a later stage still, certain epithelial cells become specially differentiated for the purpose, frequently accumulating pigment in order to absorb the light preferentially.

Primitive vision was thus merely an intimation of a change in the environment. There was no image formed because there was no focusing mechanism; there were merely simple cells adapted to appreciate the presence or absence of light. This may be called the stage of *photo-reception*. When these cells became scattered all over the body, some degree of localisation of the direction of the light became possible, and with this came the ability to orientate the body with respect to the incident light. Thus was introduced the stage of *photo-direction*, a faculty which survives in man in the close association of the eyes with the vestibular apparatus and their importance in the control of posture. At this time there was no analysed sensory response showing appreciation or any attempt at interpretation; for this purpose reliance was placed upon those senses which were more fully developed at this early stage—that of smell, the chemical sense, and the tactile sense.

For example, the scallop has numerous visual cells round the edge of its mantle, and if these are stimulated by the "sight" of its great enemy, the starfish, no response except an awareness of the presence of something is elicited, and no attempt at flight is made; but whenever some extract of starfish is added to the water in which the animal lies, the scallop immediately runs away. In the case of pecten, no matter what the image is, there is no response until the object moves, and any movement of any object excites the same response—a protrusion of the tentacles. These are endowed with organs of chemical and tactile sensibility, and they explore the object "intelligently," and on the result of their findings the animal either eats or flees.

One way of obtaining an image that could be appreciated is to multiply these primordial visual cells in order to have a large number of simple "eyes" grouped together, so that by having many elementary images, some conception of the object could be appreciated. Such a course determined

Digitized by Illinois College of Optometry Library

the evolution of the compound eyes of insects. A more efficient way of attaining the same end is to group the many individual elements into one co-ordinate whole, and to produce a sharp and well-defined image upon such a mosaic of receptive cells by placing in front a suitable optical system which focuses the light to a point upon it. Such a combination forms the eye of vertebrates. If this system can be made adjustable so that light from varying distances can be accurately focused upon the sentient cells, the eye will become a much more serviceable instrument; and if in addition the two eyes are movable, so that they can be accurately directed upon the same object and can follow it in its movements through space, their utility will be further increased. It is such a system as it is found in its greatest development in man—the refractive mechanism of the eye which focuses the light upon the retina, its accommodative power which modifies the refraction, and the muscular action which co-ordinates the movements of the two eyes—that it is proposed to study in this book. From the position and importance of a secondary sense, vision has arisen to a dominant position in the life and activities of man, controlling much of his usefulness and happiness; and the scope and importance of the subject can best be realised from a consideration of the incapacitating and unpleasant results which may arise from defects in his optical apparatus.

Digitized by Illinois College of Optometry Library

CHAPTER II

EYE-STRAIN

It has frequently been remarked that with all its obvious advantages a highly specialised system often carries with it the defect that it is less capable of withstanding long-continued and excessive strain, and is more prone to show weakness or to collapse than a cruder, more plastic, and less differentiated mechanism. The visual apparatus of civilised man provides an apt illustration of this generalisation. There is no organ in the body which shows a finer or more intricate structure, or which depends for its efficient working to a greater degree upon minutiæ; there is none which subserves a higher or more exacting function. Moreover, the eye as the dominant sense organ and the instrument of epicritic vision is a development only recently established in phylogenetical history; while the exigencies of the struggle for existence and the exorbitant demands of a complex and artificial civilisation have put upon it highly a-physiological strains and stresses, whose extent is difficult to appreciate adequately. Although, from long custom, we accept the conditions under which we live to-day as normal, it by no means follows that the eye has evolved to cope with them, and the fact that it is able as a rule to meet the demands which are made upon it, is a compliment of no mean order to the extreme adaptability of living organisms. It is not surprising, therefore, that of all the ailments which interfere with the smooth running of the human machine, eye-strain in one form or another is probably the most common.

The importance of the relief of eye-strain in the health and happiness as well as in the economic value of the indi-

Digitized by Illinois College of Optometry Library

vidual, is now widely recognised; but at the same time it is surprising, when the various constitutional troubles to which it may give rise are remembered, that the mention made of it in the majority of works on general medicine is so slight and casual. Tradition dies hard; and this apathy is probably due in large measure to the complete neglect with which the subject was regarded until comparatively recently by legitimate practitioners, as well as to its subsequent exploitation in overdrawn terms by extremists. It is fortunate that uncritical teaching has never been received with great acceptance in medicine; but the ill-advised statements of a few should not result in our ignoring the fact that errors of refraction, more especially of small amount, anomalies of accommodation and convergence, and a lack of balance between the extrinsic ocular muscles, are the unsuspected cause of much suffering. Too often in the diagnosis of such cases the ocular cause of the trouble is neglected, or thought of ultimately as a last expedient, when frequently it should have been considered and remedied first.

Two factors contribute largely to this failure in rational treatment. From the symptoms offered by the patient, eye-strain may not easily be suspected, for many of them are referred and seem to bear little or no relation to an ocular origin. Further, in a great many cases the vision, as judged by the patient's own standard, may be unimpaired, or indeed, it may be considered above the normal. But it is to be remembered that as a general rule the most distress is caused by errors so slight that they readily escape detection unless they are looked for specially. When a gross anomaly exists and vision is blurred and indistinct, the visual apparatus reconciles itself to its disability without any attempt to improve the condition; the matter thus begins and ends with an impairment of vision; the diagnosis is apparent and the treatment obvious. But when the error is small the patient is able to rectify it to a greater or less extent by muscular

Digitized by Illinois College of Optometry Library

effort ; this he continually attempts to do to the best of his ability, and the constant strain thus involuntarily imposed upon him brings on muscular and nervous fatigue with its attendant train of reflex symptoms. It is not the error itself which causes the trouble so much as the continuous effort called forth automatically in the attempt to correct the error. The physician may suspect that a symptom-complex may be attributable to the eyes, and on his suggestion the patient will protest that his vision is excellent ; but careful examination will show that an unsuspected small error of refraction, or a slight degree of muscular imbalance is present, and its correction will frequently result in an equally unexpected and dramatic relief.

The Symptomatology of Refractive Errors

The Symptoms of Gross Refractive Errors.—The disturbances which are caused by gross errors in the optical system of the eye are largely limited to a failure of visual acuity and its immediate consequences. Apart from the physical disability and the economic disadvantages which this necessarily entails, such a condition usually reacts upon the psychological outlook of the individual. This is most strikingly seen in children, especially in short-sighted children who are allowed to grow up with the error uncorrected. They develop in a limited world wherein they are at a considerable disadvantage in comparison with others, a handicap which may entail a seeming limitation of intelligence and a curtailment of interests which are frequently put down to stupidity and backwardness, or to naughtiness, while they are really due to the physical defect. Where the error is adequately corrected, these considerations do not necessarily apply ; and, even where it is not, in many instances interests suitable to their case and other compensatory factors more than make up for their disability. But as a general rule in these cases, much that is going on in the world—especially the more

Digitized by Illinois College of Optometry Library

subtle things—escapes them ; and deprived of the means of observing the niceties and refinements in their intercourse with others, they either tend to hide away within themselves, or, taking refuge in the other extreme, their manner may become blatant and self-assured. They are seldom practical, and frequently they betray a certain awkwardness physically ; too frequently their physical characteristics are reflected in their mental outlook. Avoiding outdoor sports and prone to introspection, debarred from free intercourse with their fellows and unable to enjoy full appreciation of them, they frequently tend to grow up with distinct mental habits and peculiarities.

We all remember the story of " Two Eyes " and " No Eyes ": " Two Eyes " who married the princess and lived in the palace, and " No Eyes " who was eventually relegated to the scullery, there to polish boots, and to take what food the servants gave him.

The Symptoms of Small Refractive Errors.—The symptoms caused by small errors—or more correctly, by the strain of the effort to compensate for the small errors—are more interesting from a medical point of view. Ranging from a mild degree of headache to symptoms simulating grave organic nervous disease, they are more complex and less easily detected, more common in their incidence, and more prolific in unfortunate results. It is these in their various forms which are usually referred to as " eye-strain." They may be conveniently considered in three classes, according as they may affect the vision, or may be manifested in the eyes themselves, or may be evident as symptoms referred to other parts of the body.

Divergent though they are, *the mechanism of these symptoms* is the same. The normal eye, as will be seen later, is adapted to receive clearly-defined images of distant objects on the retina without effort or strain ; but when attention is turned to objects near at hand, the refractive power is altered by an effort of the ciliary muscle, while at the same

Digitized by Illinois College of Optometry Library

time the eyes themselves are converged upon the object of attention by the internal recti. These two actions are synkinetic, in that, controlled by the same nerve, in normal circumstances they are continuously related to each other in degree. Whenever these ideal conditions are upset in one way or another, strain tends to result. In the case of a long-sighted individual the eye at rest receives only blurred images on the retina, and in order to get clear images he has to increase his refractive power by continually forcing his ciliary muscle into activity : the nearer the object the more powerful must be the effort. A short-sighted individual, on the other hand, has to bring an object close up to the eyes in order to see it distinctly, and since the power of convergence is thus unduly overtaxed, the strain is thrown upon the internal recti. In each case the effect of this muscular strain is increased by the attempt to dissociate the normal synkinetic action of these related functions. If, in addition to either of these, the optical systems of the two eyes are different so that the correcting effort has to be unevenly distributed, the strain will be greater ; and if, again, astigmatism co-exists, so that the refraction of one or both eyes is irregular, a further complication is introduced. Again, where the extra-ocular muscles are incorrectly balanced, so that the eyes at rest are not parallel in direction, the efforts to bring them into line in order to obtain binocular vision is another prolific cause of strain. Lastly, to the distress caused by over-burdened muscles there is added the fatigue of the interpretation of blurred images in the higher cortical levels of the visual apparatus, and the combination of the two factors may be sufficient to cause considerable suffering.

It is obvious that in such a cycle the breaking-point will be reached more readily in the feeble than in the robust. It is true that symptoms do not by any means appear in proportion to the gravity of the causal defect, and that they vary from individual to individual to the most surprising

Digitized by Illinois College of Optometry Library

degree without any apparent cause, this one showing no sign at all of trouble, and that one, with apparently equal cause, and seemingly equally constituted, complaining bitterly; but as a general rule two types of cases are strikingly common. The first of these are the neurasthenic and those with an already unstable and irritable nervous system, women with pelvic disease especially during menstruation or at the menopause, or even normal people during a period of prolonged mental worry and anxiety. To many of these, glasses are of inestimable value, in that they remove one cause of irritation from an over-taxed nervous system. Secondly, in the debilitated and in those convalescing from an acute illness, or in women after a confinement and during lactation, fatigue which under normal circumstances would be barely appreciated now readily manifests itself, and an optical error which would give rise to no symptoms of discomfort were they in robust health may become acutely felt, and may necessitate the use of glasses, which may frequently be discarded at a later date under happier circumstances. Indeed, in some such cases the ciliary muscle may not be able to perform a normal amount of work without showing signs of distress, and symptoms of eye-strain may make themselves evident in the absence of any error whatever in the optical system.

(1) *Visual Symptoms.*—As a general rule, it may be taken that in the case of small refractive errors the actual visual acuity forms little or no reliable guide to the ocular condition, for the defect may be remedied by the patient more or less completely. In fact, it is frequently true that the symptoms are most marked in these cases where the vision remains good, that is, where the defect is compensated. One person will live placidly and comfortably with a small degree of astigmatism and considerably reduced vision, while another more highly organised, suffering the same disability, will attain normal or hypernormal sight—and pay for it. There frequently comes a time, however, either in periods of un-

Digitized by Illinois College of Optometry Library

usual strain, or during a temporary deterioration of the general health or vitality, when fatigue comes on and the visual acuity fails. This is especially seen in those who use the eyes much for reading or the study of small objects over long periods of time, while fine sewing, the cinema or the theatre, sight-seeing, motor driving in the distractions of confusing traffic, or any relaxation or employment which calls for a high degree of visual acuity combined with attention or anxiety, are frequently the causes of such a breakdown. A sense of confusion and a temporary blurring of vision is experienced, the letters when reading, for example, appearing to run together. Here the ciliary muscle gives up any attempt to focus and the image becomes indistinct, or the external muscles slip back into their original condition of rest and diplopia results. This may be momentary and pass off, to recur again at more frequent intervals, the eyes gradually becoming tired and the lids heavy, while a sensation of weariness or drowsiness makes itself progressively felt and renders continued attention difficult or impossible. A relaxation of attention brings relief, but a resumption of the matter at hand induces a repetition of the trouble, until ultimately the individual is tempted to give up the attempt from annoyance or exhaustion.

(2) *Ocular Symptoms.*—The symptoms which affect the eye itself are sometimes spoken of collectively as *asthenopia.*

It has been suggested that the term asthenopia be restricted to denote "retinal fatigue." This definition is difficult to understand, for there is no reliable evidence to show that a true physiological fatigue of the retina exists. Excessive bright light brings about alterations in the mechanism of the working of the retina and changes its excitability, but these changes differ completely from fatigue as the term is generally understood. There are many cases where the excitability of the retina appears to be definitely above the normal, when a small excess, or even an average amount of light gives rise to considerable annoyance and a sensation of irritability. These symptoms, however, are inaccurately designated as "fatigue"; they are largely functional in nature and psychological in origin.

Digitized by Illinois College of Optometry Library

The ocular symptoms associated with eye-strain are directly due to the increased muscular work which the defect invokes and the discomfort of the resultant muscular fatigue, to which is added the effects of a condition of more or less permanent vascular engorgement determined by this state of sustained and forced activity. Subjectively, especially after long periods of close application to work, the eyes feel tired, hot and uncomfortable; temporary relief is obtained by resting or by rubbing them, but if the work is persisted in, the vague discomfort gives place to a feeling of actual strain, and this develops into pain. Pain in the eyes unconnected with inflammation is almost invariably due to eye-strain, and rarely to any deep-seated disease. It usually is mild and dull and aching, but may on occasion be severe and acute; it may be situated in the eyes themselves or be located more deeply in the orbits, or spreading therefrom, become referred as a general headache.

Objectively, the eyes frequently have a typical appearance. The continued state of irritability and congestion brings about an unhealthy condition of the lids and conjunctivæ. Blepharitis and recurrent styes are common, and low-grade infections of the conjunctiva readily establish themselves and tend to become chronic in spite of the usual local medicaments, the eyes having a characteristic look, watery, suffused, and bleary. This is especially notable in children, in whom an intractable blepharitis or conjunctivitis should always suggest an examination of the refraction. Such low-grade infections are probably accentuated and prolonged by the child constantly rubbing its eyes with its fingers; the eyes feel strained and sore, and a child's hands are rarely clean. In the more pronounced degrees a "red eye" is common, and there is often some ciliary tenderness; the fundus may even appear somewhat congested and the disc pink, while the retinal veins are sometimes engorged and full.

Eye-strain has at one time or another been credited with a share in the ætiology of almost every ophthalmic disease. Frequent

Digitized by Illinois College of Optometry Library

mention is made of it in association with iritis and irido-cyclitis, with glaucoma, and even with cataract. The factors determining the incidence of these diseases are usually complex and often not a little obscure, and that continued and excessive eye-strain may have some small predisposing influence on the occurrence of some cases is difficult altogether to deny ; but to ascribe to it an important or determining share in the ætiology of any of them seems to be laying undue stress on what should more reasonably be regarded as an accidental and contributory influence.

(3) *Referred Symptoms*.—The commonest symptom associated with eye-strain is *headache*. This occurs in almost every possible variety, and may be referred to any part of the area of distribution of the fifth nerve. It may be localised around the region of the eyes ; it may be frontal, temporal, or vertical, or the reflex irritability may spread down the bulbo-spinal root of the trigeminal nerve, and, causing hyperæsthesia in the upper cervical segments of the cord, bring about an occipital headache, or the pain may extend down the neck or even into the arms. It may remain limited to any part, being associated frequently with a tender area in the vertex or the temple, but as a general rule, when thus limited, it occurs as a " brow-ache " over the immediate neighbourhood of the eyes. Alternatively, originating in one region, it may extend, sometimes remaining strictly unilateral, but more usually it develops a cumulative and expansile character, and becomes generalised. It varies widely in nature : sometimes it is superficial and resembles a cutaneous hyperæsthesia, sometimes deep-seated and boring, or full and throbbing ; it may be a dull and heavy ache difficult to describe or to localise at all accurately, or it may be neuralgic in nature, sharp, shooting, and lancinating. In its incidence it may be permanent or periodic, or it may come on at quite irregular intervals. It may or may not be definitely associated with the use of the eyes ; usually it is so, and makes itself most evident in the evening after a day's work, especially when the condition of eye-strain is aggravated by inadequate or badly distributed artificial

Digitized by Illinois College of Optometry Library

light. On the other hand, it frequently comes on in the morning after a night's rest and sleep. Occasionally, appearing at periodic intervals, it has all the characteristics of a typical attack of true migraine. Conforming thus to no type and simulating most, the headache of eye-strain is difficult to diagnose with certainty; the only rational course to adopt is to examine the eyes as a matter of routine in all cases where such an origin might be suspected. Usually of a mild nature, giving rise to annoyance and exasperation rather than actual pain, it may be completely incapacitating on occasion, or by its constancy and persistency it may suggest organic central nervous disease. No case of obscure headache should be treated on general medical lines without first eliminating the possibility of eye-strain as being one at least of the factors in its ætiology.

The referred disturbances caused by eye-strain are not limited to an irritability of the fifth nerve and its immediate effects, but may occasionally extend to produce further symptoms. These optical errors are likely to cause vestibular upset, at times bringing on dizziness and disorientation and a sensation resembling sea-sickness, which frequently culminate in nausea and even vomiting. It is this symptom-complex, when it occurs periodically associated with an acute and incapacitating headache, which resembles a true migraine. The near association of the descending root of the fifth nerve with the nucleus of the vagus in the medulla may be responsible for accentuating these gastric disturbances, and tend to perpetuate a condition of anorexia and mild dyspepsia. A similar reflex irritability of the seventh nerve may occur, which may be manifested in spasmodic movements of the facial muscles, especially those associated with the lids. Rarely, the disturbance may spread to involve the upper cervical segments of the cord and give rise to a spasmodic torticollis. This is most frequently seen in children in whom such habit spasms, tics, and choreiform movements are often associated with an

Digitized by Illinois College of Optometry Library

error of refraction, and can be cured by its correction in combination with suitable measures directed against any other concomitant sources of irritation which frequently co-exist. Sympathetic disturbances also occur, the most common of which are localised vaso-motor disturbances or a hyperidrosis limited frequently to one or other side of the head.

A condition of eye-strain has also a tendency to reflect on the general health and mental well-being, especially in those who, from instability of temperament or from over-work, are living too freely upon the margin of their reserves. It is a fertile cause of the prolongation of neurasthenic states ; but it is not alone in the neurotically inclined or in those with an unstable nervous system that it makes its influence felt, but also in those highly-organised individuals who enrich more particularly the intellectual spheres of life, and who find happiness only when they are spending them-selves lavishly. In these the wasteful expenditure of energy in the continuous attempt at correction may act as the final straw in bringing about a condition of nervous prostration or irritability of temper. Fatigue readily comes on and ultimately becomes more or less constant, insomnia and depression result, and starting their daily duties with a large deficit, they may lose much of the verve and vivacity of life.

There is a tendency among some writers to ascribe to errors of refraction very much more profound effects than these. They are spoken of as being the cause of migraine, chorea, and epilepsy ; as being an important factor in the ætiology of constipation, gastric ulcer, and in the liability to succumb to tuberculous or any other infection ; or as having a determining influence in the occurrence of alcoholism, suicide and crime. The causes of most of these are complex and far-reaching. It is true that eye-strain may cause much worry and unhappiness, and it is certainly the case that it may lower the general vitality considerably ; it may reason-ably occur that a person is placed in circumstances with which

Digitized by Illinois College of Optometry Library

normally he may just be able to deal, but the additional distress of an optical error carries matters to the breaking point. In these cases, however, the influence of the optical defect is incidental and occasional rather than primary and essential. A refractive error may bring about a train of symptoms resembling migraine, but there seems to be little adequate evidence that it can be considered as a cause of true migraine, and less that its correction has ever resulted in a cure of the condition : certainly as an irritating factor to a susceptible nervous system it may be considered an exciting cause which may aggravate or prolong a migrainous state, and, equally certainly, in all such subjects the eyes ought to be carefully tested and corrected. Similar considerations apply to chorea and epilepsy ; but with regard to the other conditions mentioned, the application seems far-fetched and fantastic.

The ophthalmologist is not alone in attributing to eye-strain more evils than, we think, can reasonably be laid to its account. We have seen that a neurotic temperament is frequently associated with the condition, and we have noted that anomalies in the optical mechanism may well be the means of the aggravation and prolongation, if not in some cases even the cause, of such psycho-pathological states. But it happens, particularly, although not exclusively, in women, that functional troubles which are without any reasonable organic basis are referred very definitely and persistently to the eyes. Such a patient will insist that she cannot use her eyes for any length of time, or that when she attempts to do so she cannot see at all. Frequently she sees spots floating about in front of them. Sensitivity to light is especially marked, and she is quite unable to bear illumination of any unusual intensity ; even in diffuse daylight she prefers to go about in dark glasses. Headache is the most frequent symptom, and its neurotic origin can frequently be recognised from the sensations she describes. A patient with a true organic headache rarely hesitates to describe his sensations

Digitized by Illinois College of Optometry Library

as those of pain pure and simple: she, on the other hand, with no evidence of emotion, will describe a sense of pressure, of emptiness, of the head opening or shutting, or of its being bored through by a nail, or being constricted by a band. These, and many more: but whatever it is, the impression is given that it is horribly unpleasant, and that she is suffering the tortures of the damned. She may have an optical anomaly, or she may not; but in either case, producing a host of glasses obtained from as many surgeons and opticians —each of which she has worn punctiliously—she will declare in a firm and quiet voice that none of them are of any use at all. Certainly any optical error she may have should be corrected with scrupulous care; but the real trouble is a pathological attitude of mind, none the less real to her, it is to be noted, because it is so, and treatment should be directed towards that with all sympathetic consideration and forbearance.

The Treatment of Refractive Errors

In the treatment of these ocular conditions the greatest essential is accuracy. We have seen that it is the small errors which give rise to the greatest systemic disturbance, and when they are giving rise to trouble and their correction becomes necessary, unless this is done with meticulous care, a small error will be perpetuated, perhaps in another form, and the symptoms will be unrelieved. Indeed, it happens that a patient with a gross error and suffering no constitutional disability therefrom, but merely complaining of defective vision, will be introduced to the headaches and annoyances of eye-strain for the first time when he has got his glasses, because his large error has been almost, but not quite corrected, leaving him in the position of one with a small error. It is fortunate that of all the branches of medicine, refraction work lends itself to the highest degree of objective accuracy.

Digitized by Illinois College of Optometry Library

Stress has been repeatedly laid upon the large part played in the symptomatology of refractive errors by the smaller defects, but it should be pointed out that every small error by no means requires correction. There is undoubtedly a tendency at the present time to do this and to provide a large proportion of the population with totally unnecessary glasses. Sometimes the habit is positively pernicious, as in the provision of convex lenses to young hypermetropes with small errors, thereby depriving them of the stimulus to accommodate. The wholesale correction of small errors of astigmatism is a more negative evil. It will be pointed out later that an absolutely normal refraction is so rare as to be considered almost as abnormal, and a small astigmatic error is present in the vast majority of people. Moreover, the eye is neither an accurately centred nor a corrected optical system, but, as we shall see later, is characterised by unknown errors of spherical, chromatic, diffractive, and astigmatic aberration. In no case is an optically perfect image formed. To correct a minute error which is not associated with definitely incriminating symptoms, especially when it is measured in the pathological condition of cycloplegia and transposed to the eye in its normal dynamic state, and when it is further warped by the optical defects inseparably associated with the fitting of glasses, is to misinterpret completely the whole economy of living organisms. Where an error is found, however, and with it are associated definite symptoms, the case is very different.

Not only is the eye to be treated as an optical instrument, but it ought always to be considered as an integral part of the body, sharing with other organs in its constitutional variations and in the effects of the ills with which it may be afflicted. The treatment of its optical defects should never be left in the hands of those who, from lack of medical training, are unable to appreciate it as being not only in the body but of it; and the mechanical devices of the optician should always be regulated by the physician's grasp of the organic

Digitized by Illinois College of Optometry Library

condition underlying the trouble, no less than by his sympathetic understanding of the demands made upon the patient and his ability to meet them adequately. In the first place, for the correction of many small errors, particularly in young people, the administration of such drugs as atropine and homatropine is necessary, and the use of these should not be left to unskilled hands. Further, many optical defects which, looked at superficially, appear simple and straightforward, are in reality early signs of diseases whose presence in their incipient stages can only be detected by those who have undergone long and specialised training; and much invaluable time may be lost, and much irreparable damage done, by improving the vision to an extent sufficient to allow the patient to carry on for a time by providing him with glasses which should never have been ordered to the neglect of the underlying ocular condition.

In addition to this, the condition of short-sight in its higher degrees may itself assume the proportions of a disease, and its treatment demands much more knowledge and experience than the ability to rectify the optical defect. In many cases, especially in children in whom the condition is progressive, it is essential that the strength and constitutional resistance of the patient be weighed, and his capacity to withstand strain be assessed; and it frequently is the case that his whole life-work and activities may have to be altered and directed in order that they may be brought within the limits which his eyes are capable of undertaking with safety. It is obvious that decisions of this nature are not to be undertaken lightly or without a due sense of responsibility.

Apart from the condition of the eyes themselves, nothing is more pernicious than the routine correction of optical defects by rule-of-thumb methods. The matter is much more subtle and far-reaching. Muscular deficiencies must be investigated and, if necessary, neutralised, and the limits of muscular work must be respected and the treatment regulated accordingly. Many symptoms which are apparently

Digitized by Illinois College of Optometry Library

caused by refractive errors or muscular anomalies would give no trouble in the ordinary course of events, and become apparent only because of ill-health or on the attempt to do more work than the individual is capable of accomplishing with safety: a frequent instance of this are the troubles of which many children complain when commencing the routine of school life. If a rest and general tonic treatment are prescribed, these symptoms frequently disappear without any help in the form of glasses. The ideal treatment, of course, is to combine the two; but if the latter alone are prescribed, and the warning of over-work as manifested in the eyes is neglected, the glasses may provide the patient with the means wherewith to struggle on until he suffers a much more serious breakdown. In many of these cases the eyes thus form a valuable index of the general state of fatigue, and from a study of their condition the work and conduct of the patient can very usefully be regulated. The adjustment of suitable lenses is not sufficient treatment in itself; the refractionist should be in a position to direct the whole life and activities of his patient—his habits, his diet, his exercise, and the manner and amount of his work. We have seen that there is little pathognomonic in the symptoms of eye-strain, and that frequently when they simulate constitutional disease, their origin in the eyes is overlooked by the general practitioner. So conversely, symptoms which may appear obviously to be due to a refractive anomaly, may be the result of an entirely different cause; and the specialist should be one who is competent to appreciate and recognise this and allow his treatment and advice to be guided by this knowledge.

The prescription of glasses is therefore not merely a matter of placing lenses in front of a patient and ordering those which give him the highest visual acuity. It is, on the contrary, a delicate operation, depending not only on a sound theoretical knowledge of the optical system of the eye, and an ability to determine accurately its refractive peculiarities, its

Digitized by Illinois College of Optometry Library

accommodative power, and the condition of its associated muscles, but it also involves an appreciation of the diseases both of the eye itself and of the body generally, especially those which manifest themselves in the central nervous system, and an ability to view in their proper perspective the physical and psychological idiosyncrasies of the patient, the purposes of his wearing glasses, his constitutional state, and his peculiar habits.

Digitized by Illinois College of Optometry Library

SECTION II

REFRACTION

CHAPTER III

THE PRINCIPLES OF REFRACTION

The Nature of Refraction.—It may be said, in general terms, that light travels through space in straight lines. It is true that recent advances in physical science have suggested that this is not strictly accurate; but for the purposes of the optical problems which we propose to consider, it may be taken to be the case. If, however, a ray of light meets a body in its passage through space, one of three things may happen to it. Some substances, for example, black bodies, *absorb* the light which falls on them: these are called opaque. Others, such as mirror surfaces, *reflect* the light backwards; while others, such as glass, which are described as transparent, allow the light, or at any rate, a considerable proportion of the light, to pass through them. In space, light maintains a constant speed of about 184,000 miles per second, but as it travels through the substance of such a transparent body it is obvious that it will encounter more resistance than it did previously, and as we would expect, this retards its progress.

In such a case, if a beam of light enters a transparent body perpendicularly to its surface, its progress will be retarded, but nothing else will happen to it. The condition of affairs may be gathered from Fig. 1. But, on the other hand, if the beam strikes the body obliquely, one edge of the advancing beam will enter the body before the other, and consequently will be retarded earlier. The condition of affairs in this case

Digitized by Illinois College of Optometry Library

will best be understood from a study of Fig. 2. At the position AB the entering beam is beginning to meet with the resistance offered by the transparent body at A, and for the

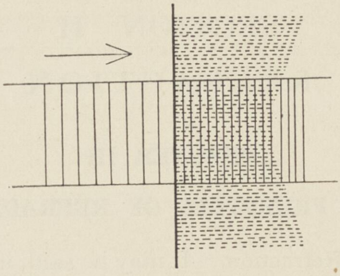


Fig. 1.—The Passage of a Beam of Light through a Transparent Body.

The spacing of the vertical lines indicates the relative velocity in the air and in the substance of the body.

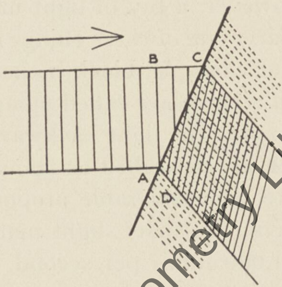


Fig. 2.—The Refraction of Light by a Transparent Body.

At the position AB, the part of the beam at A enters the body. Owing to the greater resistance and consequent diminished velocity, the beam is bent round during the period AD, BC. Thereafter, meeting with a uniform resistance throughout, it travels through the body as a parallel beam.

next part of its course the part of the beam which is within the body will necessarily travel more slowly than that which, being outside, is still unimpeded. The distances travelled in the same interval of time are therefore unequal, AD being

Digitized by Illinois College of Optometry Library

less than BC, and consequently the front of the beam is swung round and its direction is changed. This phenomenon of the bending of light as it passes from one transparent medium to another of unequal density is known as *refraction*.

We can vary the amount by which the beam of light is bent in two ways. In the first place, since the bending is dependent upon the retardation of the light, the more resistance the body offers the more slowly will the light be made to travel, and consequently the more acutely will the rays of light be bent. This property of offering resistance to light is known as *optical density*, and it varies within wide limits with different substances. For practical purposes the universal medium through which light travels is the air, and so the optical densities of different substances are usually compared with that of air taken as a standard. The refractive power of a substance in comparison with that of air is spoken of as its *refractive index* : thus the refractive index of air is 1, that of water 1·33, that of crown glass is 1·5, and so on.[1]

In the second place, the amount of bending may be altered by varying the obliquity at which the beam of light enters the body : it is obvious from a consideration of Fig. 2 that the more acute the angle at which the incident rays strike the surface of the body, the greater will be their deviation. In practice it is usually not feasible to alter the direction of the rays of light, and so the refractive power is varied by altering the obliquity of the surface of the transparent body.

By these means light can be manipulated to a considerable extent, and instead of travelling, as it ordinarily does, in straight lines in all directions, it can be made to proceed in well-defined paths. It is the essential function of all optical apparatus to turn the course of rays of light from their original indiscriminate directions into definitely determined paths, and we will proceed to study the methods used for this purpose by the refractive system of the eye.

Refraction by a Plate with Parallel Sides.—When parallel

[1] See Appendix I.

Digitized by Illinois College of Optometry Library

rays of light fall perpendicularly upon a glass plate, the front of the beam will be equally retarded throughout its extent ; no deviation therefore occurs, and consequently when it

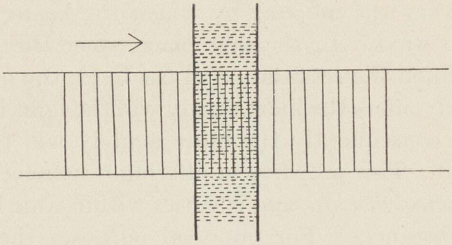


FIG. 3.—REFRACTION OF LIGHT THROUGH A GLASS PLATE.

When a beam of light strikes a glass plate with parallel sides, it is retarded while traversing the plate, and then travels on unaffected.

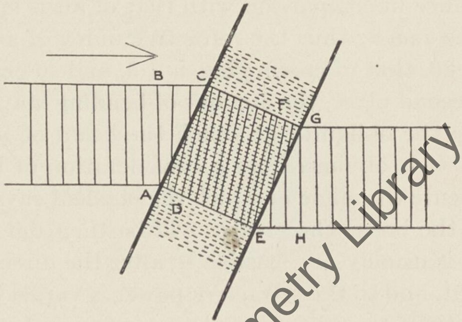


FIG. 4.—REFRACTION OF LIGHT THROUGH A GLASS PLATE.

When a beam of light strikes a glass plate obliquely, the portion which enters first at A meets with resistance. The beam is therefore bent during its course AD, BC. After the position DC is reached it travels as a parallel beam through the substance of the plate. At EF an opposite process takes place, involving an equal amount of refraction, with the result that at GH the beam travels on in the same direction as before, but displaced from its original path.

leaves the plate on the other side, the beam proceeds unaffected (Fig. 3).

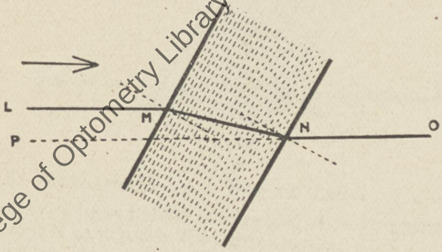
But when parallel rays fall obliquely upon a glass plate, we have seen that their direction is changed on account of the

Digitized by Illinois College of Optometry Library

at once regains its original veloc...

ERRATA

The line L M N O should traverse the glass plate as represented in this errata slip, and not as in Fig. 5



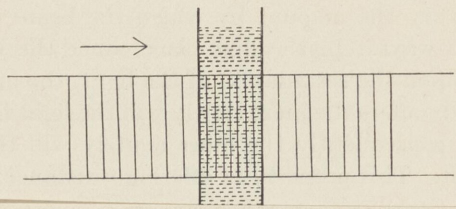
p. 244, line 5.—" squinting " should read " non-squinting."

line 23.—" it " refers to the sound eye.

Digitized by Illinois College of Optometry Library

...although its path has been changed, the emergent light is parallel...

rays of light fall perpendicularly upon a glass plate, the front of the beam will be equally retarded throughout its extent ; no deviation therefore occurs, and consequently when it



it travels as a parallel beam through the substance of the plate. At EF an opposite process takes place, involving an equal amount of refraction, with the result that at GH the beam travels on in the same direction as before, but displaced from its original path.

leaves the plate on the other side, the beam proceeds unaffected (Fig. 3).

But when parallel rays fall obliquely upon a glass plate, we have seen that their direction is changed on account of the

Digitized by Illinois College of Optometry Library

retardation of one edge of the beam (A, Fig. 4) before the other (B). When the entire width of the beam has entered the substance of the glass at CD, all rays will be equally retarded throughout, and consequently, travelling at a uniform, though lessened speed, they will once more proceed as a parallel beam, running, however, in a different direction through the thickness of the plate until the other surface is reached. Here exactly the opposite process takes place. At the position EF the edge of the beam at E, on entering the air, at once regains its original velocity, while at F the resistance of the glass is still felt. This inequality of speed obtains until

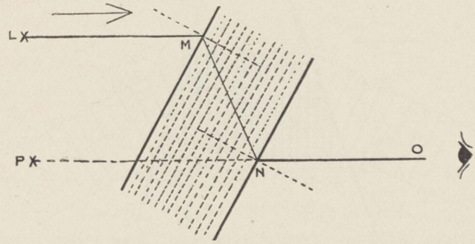


Fig. 5.—Refraction of a Ray of Light by a Glass Plate.

The ray of light LMNO is refracted at M as it passes from air to glass, and N as it passes from glass to air.

When an eye is situated at O, the source of light, L, appears to come from P.

the position GH is reached, when the entire beam once more travels on as before. Since the processes at either side are exactly the reciprocals of each other, the beam is bent to an equal and opposite degree, and therefore, although its path has been changed, the emergent light is parallel to the incident light.

If we consider the course of a single ray (Fig. 5), and draw perpendiculars at the two points M and N where it cuts the surfaces of the plate, it becomes evident that when light passes obliquely from a medium of less density to one of greater density, it will be refracted towards the perpendicular; if it passes from one of greater to one of less density

Digitized by Illinois College of Optometry Library

it will be refracted from the perpendicular, the amount of refraction depending on the difference between the densities of the two media. Since the degree of refraction in passing between the same two media is always the same, the emergent ray, although it is displaced, runs parallel with the incident ray. Now the phenomena of refraction enter but little into our everyday experience, and so we tend to ignore the optical effects to which they give rise, and are accustomed to project objects visually along the direction of the rays of light as they enter the eye. Consequently, if L be a luminous

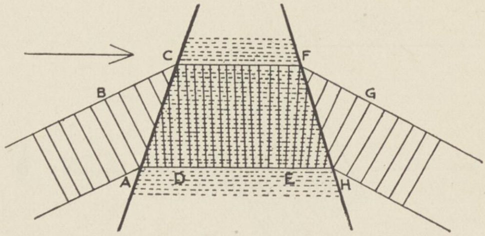


FIG. 6.—REFRACTION BY A GLASS PLATE OF NON-PARALLEL SIDES.

The two sides AC and HF are not parallel. The beam is therefore bent from the position AB to DC on entering the plate, and from the direction EF to HG on leaving the plate. Its original direction is thus completely changed.

object and O the observer's eye, the object will appear to be situated at P.

Refraction by Prisms.—We have seen that when light passes through a medium with parallel sides, the incident rays and the emergent rays are parallel; but if the sides of the medium are not parallel, the direction of the rays must also change. Thus in Fig. 6 the incident beam of light is retarded at A so that AD is shorter than BC; it is therefore bent round and runs through the substance of the glass until it reaches the position EF. Here the upper part of the beam (FG) accelerates on entering the air, while the lower part (EH) is still retarded; consequently the beam is bent round

Digitized by Illinois College of Optometry Library

further in the same sense and is deviated out of its original path altogether.

Such a medium is typified in the *prism* (Fig. 7). It is made up of two sides, AB and AC, meeting at an apex, A, and joined by a base, BC. The angle between the two sides at A, which denotes the angle at which the two refracting surfaces are inclined, is called the *angle of refraction.* Since a ray of light is bent towards the perpendicular on entering a dense medium (glass) from a rare one (air), the incident

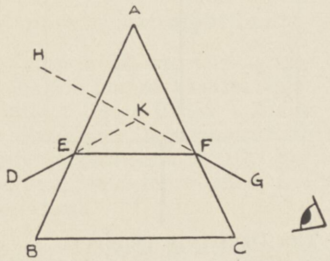


FIG. 7.—REFRACTION BY A PRISM.

ABC is a prism with the apex at A, the base BC, and the sides AB and AC. The angle of the prism is BAC.

A ray of light DEFG is refracted at E and F as in Fig. 6. The total amount of refraction, that is, the difference in direction between DE and FG, is represented by the angle DKH (the angle of deviation). If the eye is at G, the source of light, D, will appear to be at H. When the ray passing through the prism (EF) is parallel to the base (BC), the ray is said to traverse the prism symmetrically.

ray will be bent towards the base as it enters the prism, as is seen in the figure, and since refraction away from the perpendicular occurs on re-entering the rarer medium, the emergent ray will be further bent towards the base as it leaves the prism. The path of the ray is thus seen as DEFG, where it is evident that the entire deviation is towards the base. The total amount of the deviation between the incident ray (DE) and the emergent ray (FG) is called the *angle of deviation*, and is represented by the angle EKH. If an observer is at G and a luminous body is placed at D, it will appear to

Digitized by Illinois College of Optometry Library

be in the position H ; thus while the light is deviated towards the base, the image is displaced towards the apex of the prism.

The Detection and Measurement of Prisms.—By utilising this phenomenon we are able to detect the presence of a

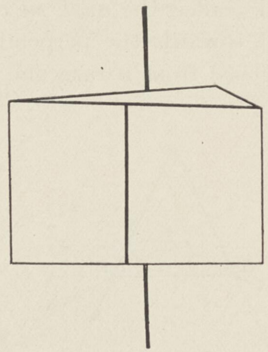


Fig. 8.—The Deviation Produced by a Prism.

An object viewed through a prism is always deviated towards the apex of the prism.

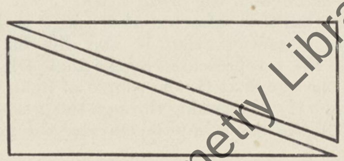


Fig. 9.—The Neutralisation of Prisms.

Two equal prisms placed base to apex act optically as a glass plate with parallel sides, and therefore produce no deviation (*cf.* Fig. 3).

prism in an optical system. We hold the glass up between the eye and any object which forms a straight line, and if the continuity of the straight line is broken, as is seen in Fig. 8, we know that a prism is present ; and since the line appears to be deviated towards the apex, we know in which direction the apex of the prism lies. The amount of displacement which is produced is an index

Digitized by Illinois College of Optometry Library

of the strength of the prism, and this can be measured by neutralising the unknown prism with which we are dealing by placing in contact with it other prisms of known strengths facing the opposite direction. Fig. 9 shows that two such prisms lying in contact together make a plate with parallel sides, and therefore, if we place a series of known prisms of gradually increasing strengths in apposition with the first, the amount of deviation produced will become less and less, until eventually, when a prism of the same strength is reached, the first will be exactly neutralised, and the object will appear once more as a straight line.

This principle is seen in the effects produced by *rotating prisms*. If two equal prisms are placed base to apex, we have seen that there is no prismatic action; if now these be rotated upon each other in reverse directions they produce the effect of a single prism of gradually increasing strength, until eventually, when they are apex to apex, a maximum effect is obtained equal to the sum of the single prisms.

The Nomenclature of Prisms.—From our consideration of the principles of refraction it follows that the amount of deviation produced by any prism depends on the refractive index of the substance of which the prism is made, the manner in which the light strikes the prism, and the size of the refracting angle. In ophthalmological practice, prisms are usually made of crown glass, and we assume that the rays fall upon the prism symmetrically (see Fig. 7); consequently the amount of deviation usually depends on the size of the refracting angle. In these circumstances the deviation produced is minimal, and where the angle is as small as it is possible to use for clinical purposes (*i.e.*, less than 10°), it is found that this deviation is equal to half the refracting angle.

It is unfortunate that the nomenclature of prisms is not uniformly standardised, for four different methods of standardisation have been suggested and are employed at various times.

(1) Prisms may be numbered according to the size of the *refracting angle*; for example, if this angle is 4°, we speak of a

Digitized by Illinois College of Optometry Library

4° prism. Since, however, the deviation produced depends also on the material of which the prism is made, we require to know the index of refraction of the glass if we are to have accurate information of the effectivity of the prism.

(2) It is more accurate, therefore, to consider the actual effect which the prism produces upon the rays of light without reference to the apical angle or the material which is used, and to measure the *angle of minimum deviation.* This is usually written °*d.*

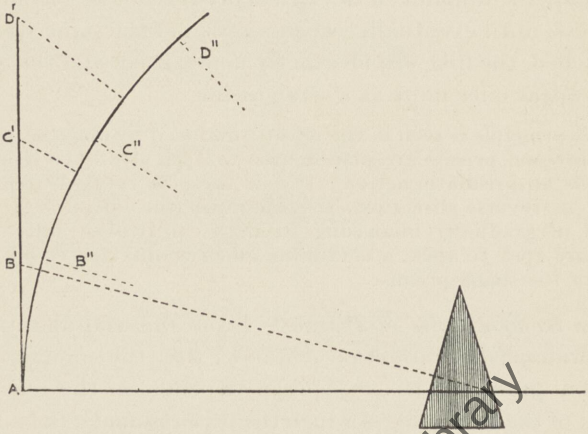


Fig. 10.—The Nomenclature of Prisms. The Centrad and the Prism Dioptre.

A straight line passing through a prism is deviated towards the apex. If the distance from the prism to A is 1 metre, the amount of deviation may be measured in prism dioptres along the line AB′C′D′ or in centrads along the arc AB″C″D″. When the distances AB′, B′C′, etc., and AB″, B″C″, etc., are each 1 cm., the dotted lines represent prism dioptres and centrads respectively.

As we have seen, in ophthalmological practice the angle of deviation is approximately equal to half the angle of refraction; a 4° prism, therefore, equals approximately a 2°*d* prism.

(3) A further method is based on the *prism dioptre* (Δ), a prism of 1Δ giving an apparent displacement of 1 cm. to an object situated 1 metre away (Fig. 10).

(4) Lastly, a method based on the *centrad* (▽) as unit is sometimes employed. The principle is the same as in the preceding case, but instead of the deviation being measured along a straight line, it is measured along the arc of a circle the radius of which is 1 metre (Fig. 10). Theoretically this is the preferable

Digitized by Illinois College of Optometry Library

method. Thus a prism of 1▽ produces a deviation of 1 cm. of arc at 1 metre.

These different notations may appear confusing; but with the weak prisms used in ophthalmology, the matter is very much simplified by the fact that a refracting angle, a prism dioptre, and a centrad are practically equal, while a deviating angle is twice this size. Thus it matters little what method is adopted. A table showing exact comparisons will be found in Appendix II.

Refraction by Lenses

The Nature of Lenses.—Since light after passing through a prism travels on in a parallel beam, it is never brought to a focus and no image is formed, but since it can be deviated by a controlled amount, we have ready to hand the essential

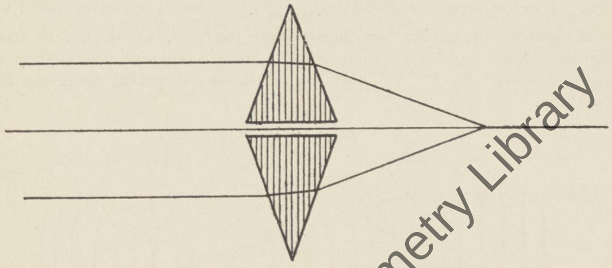


Fig. 11.—Refraction to a Focus by Two Prisms.

Two prisms placed base to base can bring two rays of light, originally parallel, to a focus.

factor necessary to bring this about. Suppose, for example, that two prisms are placed base to base (Fig. 11) it is evident that two rays which were originally parallel can be brought to a focus. If this effect is multiplied several times (Fig. 12), several such rays are similarly focused; and if we carry on the process indefinitely, and combine an infinite number of prisms in a similar arrangement, the sides of the individual prisms become infinitely small, until eventually they merge

Digitized by Illinois College of Optometry Library

into one another and form one uniform curve. At this ultimate stage all parallel rays of light will be focused at a point (Fig. 13); here the formation of an image occurs, and the arrangement of prism-elements becomes a lens. A lens

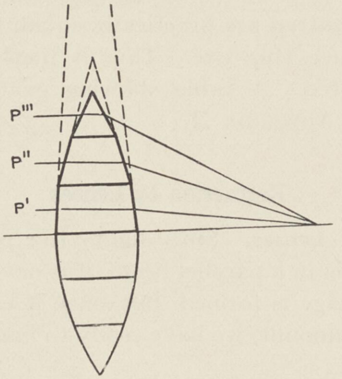


FIG. 12.—REFRACTION OF LIGHT TO A FOCUS BY A SYSTEM OF PRISMS

A system of prisms arranged base to base, as shown in the figure, refract light to a focus at F. Such a system constitutes a convex lens. P′, P″, P‴ may be taken as the prism-elements in the lens.

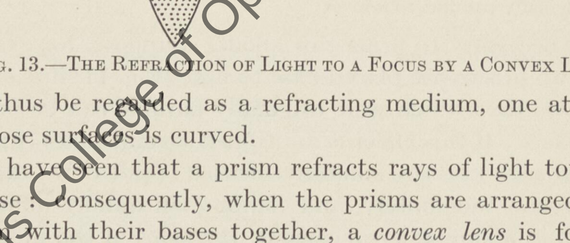


FIG. 13.—THE REFRACTION OF LIGHT TO A FOCUS BY A CONVEX LENS.

may thus be regarded as a refracting medium, one at least of whose surfaces is curved.

We have seen that a prism refracts rays of light towards its base: consequently, when the prisms are arranged in a system with their bases together, a *convex lens* is formed which converges the incident light to a point. When the

Digitized by Illinois College of Optometry Library

prisms are arranged in the opposite way so that their apices are together, a diverging effect is produced (Fig. 14), and a

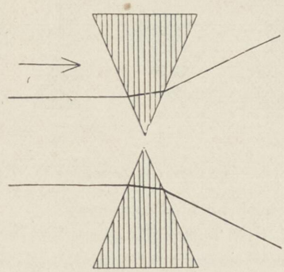


FIG. 14.—THE REFRACTION OF LIGHT BY TWO PRISMS.

Two prisms placed apex to apex refract light in a diverging manner.

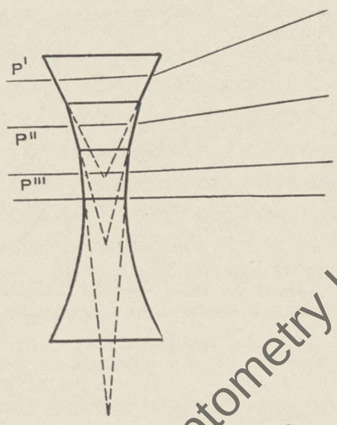


FIG. 15.—REFRACTION OF LIGHT BY A SYSTEM OF PRISMS.

A system of prisms arranged apex to apex, as shown in the figure, refract light in a diverging manner. Such a system constitutes a concave lens. P′, P″, P‴ may be taken as the prism-elements, in the lens.

concave lens is formed (Fig. 15). Although the incident light is not converged to a point in this way, it will be seen later that such a diverging action is a necessity in many optical systems. Lenses are of many varieties, but no

Digitized by Illinois College of Optometry Library

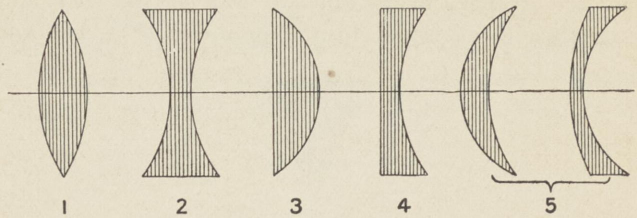


FIG. 16.—TYPES OF SPHERICAL LENSES.

1. Biconvex lens, with both sides convex.
2. Biconcave lens, with both sides concave.
3. Plano-convex lens, with one side plane, the other convex.
4. Plano-concave lens, with one side plane, the other concave.
5. Meniscus lenses :
   Convex meniscus; meniscus-shaped with the greatest curvature convex.
   Concave meniscus; meniscus-shaped with the greatest curvature concave.

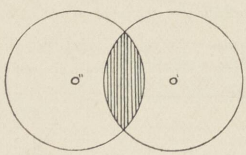


FIG. 17.—A biconvex lens may be considered as formed by the intersection of two spheres whose centres are O′ and O″.

FIG. 18.—A plano-convex lens by the intersection of a sphere by a plane surface.

FIGS. 17 AND 18.—THE FORMATION OF CONVEX LENSES.

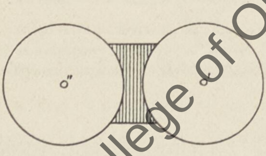


FIG. 19.—A biconcave lens may be considered to be formed by the approximation of two spheres whose centres are O′ and O″.

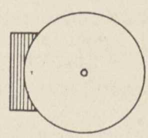


FIG. 20.—A plano-concave lens, by the approximation of a sphere and a plane surface.

FIGS. 19 AND 20.—THE FORMATION OF CONCAVE LENSES.

Digitized by Illinois College of Optometry Library

matter how intricate the curvature of their surfaces, they can all be resolved into a system of prisms. The ones most commonly used in ophthalmic practice are spherical and cylindrical with either convex or concave surfaces or combinations of these. They are illustrated in Fig. 16.

Refraction by Spherical Lenses.—The theory of lenses, if we neglect their thickness, is simple: this we can do in most cases for ophthalmological purposes. A spherical lens has one or both of its surfaces curved in the form of a sphere. The formation of a biconvex lens may be understood from Fig. 17, of a plano-convex lens from Fig. 18, of a biconcave lens from Fig. 19, and of a plano-concave from Fig. 20. The centre of the sphere, of which the surface forms a part, is called the *centre of curvature* (O), and the radius of the sphere is called the *radius of curvature*.

In discussing the theory of lenses we shall take the liberty of assuming certain theoretical postulates. Thus in the following pages we shall imagine that rays of light emanating from a point can be reassembled at another point, whereas, as will be pointed out later, this assumption cannot be reconciled with the actual facts. We shall see that aberrations or errors occur in natural conditions which render such a purely mathematical concept impossible. Further, for the moment we shall assume that the lenses with which we are dealing are infinitely thin; but such a lens, of course, is never realised in practice. Although we are in this way inventing a system of mathematical imagery, the liberties which we are taking are largely extenuated by the fact that, in the first place, a point image would be useless for physiological purposes, while, in the second, the lenses which are used in ophthalmological practice are all relatively thin and of low power. When thick lenses of high power are used, the errors and aberrations introduced make their applicability extremely limited. The matter will be dealt with at a later stage; but it is well to realise that in a sense we are dealing with theoretical fiction, a circumstance which, unless it is

Digitized by Illinois College of Optometry Library

borne in mind, may expose us to the danger of overstepping the border line between truth and half-truth.

In the case of a *convex lens*, we have seen that parallel rays falling upon it are rendered convergent. There is one small element in the centre which may be considered to have parallel sides (Fig. 21); it thus acts as a parallel plate, and the central ray which passes through it is therefore not refracted. The line of this ray is called the *principal axis* of

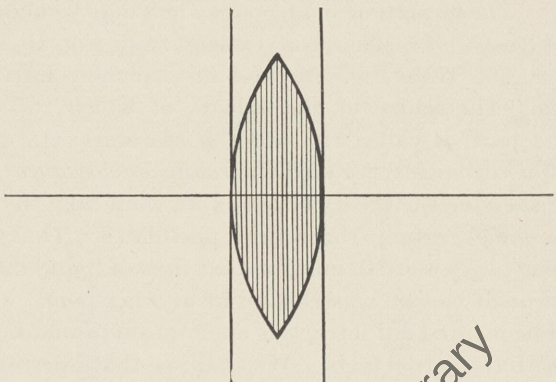


FIG. 21.—THE PRINCIPAL AXIS.

The central part of the lens through which the principal axis travels may be considered to be a plate with parallel sides. The ray of light traversing this is therefore not deviated (*cf*. Fig. 3).

the lens. If the beam does not strike the lens transversely, but obliquely, there is again one central ray which is not converged (Fig. 22). PQRS represents such a ray, since from the figure it will be seen that parallel tangents can be drawn at the points where it meets the two surfaces, Q and R, showing that this element of the lens can be considered to act as a plate with parallel sides. Such a ray, therefore, although it is slightly refracted, as in traversing a plate obliquely, leaves the lens parallel to its original direction; and if the lens is thin, this slight refraction may be neglected, and it may be considered to proceed in a direction continuous with

Digitized by Illinois College of Optometry Library

that of the incident ray. Such a ray is spoken of as occupying a *secondary axis*, and the point O which forms the centre of the optical system of the lens, where all the secondary axes meet the principal axis, is called the *optical centre;* all rays which pass through it may thus be considered to be undeviated.

It is to be noted that the optical centre does not always correspond with the geometrical centre of the lens; it need not, indeed, be inside the lens at all. It is so in a biconvex or biconcave lens; it is situated on the convex or concave side of a plano-convex or

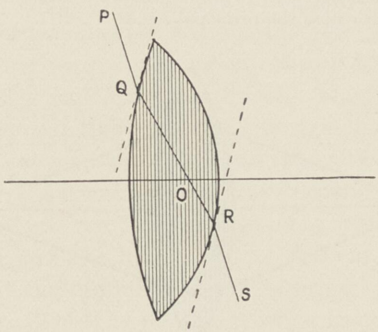


Fig. 22.—A Secondary Axis.

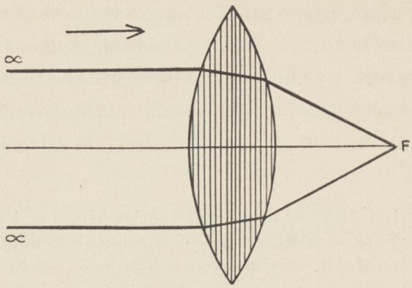
Any ray (PQRS) passing through the optical centre (O) may be considered as traversing a plate with parallel sides. PQ is thus parallel to RS. QR is a secondary axis (*cf.* Fig. 4).

-concave lens; and in a meniscus it lies outside of the lens altogether.

Apart from the rays forming these axes, all the rays of light incident upon the lens are deviated, and consequently they must meet (theoretically) somewhere. Rays from a luminous point are thus brought to a *focus*, and a collection of foci corresponding to all the luminous points of an object comprises an *image*. It is of great importance to be able to determine the position and nature of the images formed by lenses under various conditions.

Images formed by Convex Lenses.—If the incident rays are

Digitized by Illinois College of Optometry Library



Figs. 23, 24 and 25.—The Focus of a Convex Lens.

Fig. 23.—The incident rays are parallel, coming from infinity; the focus (F) is called the principal focus.

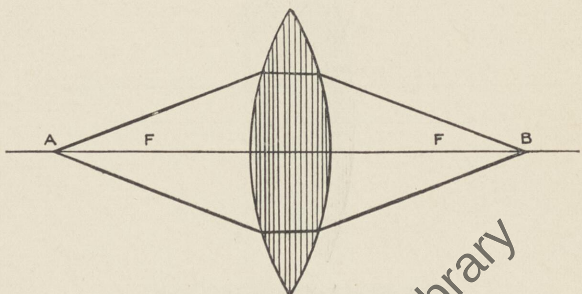


Fig. 24.—The source of light (A) is between infinity and F; the focus is at a point, B, a corresponding distance on the other side of the lens. A and B are conjugate foci.

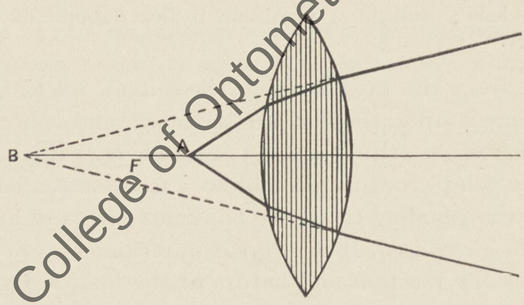


Fig. 25.—The source of light (A) is between F and the lens; the focus is at a point, B, behind the source of light. B is a virtual focus.

Digitized by Illinois College of Optometry Library

parallel, that is, if they come from an infinite distance, they will be converged upon a single point on the other side of the lens : at this point the image will be formed (F, Fig. 23). This point is known as the *principal focus*, and its distance from the lens is called the *focal distance* or *focal length*. This distance is found to be one-half of the radius of curvature of the lens.

Rays coming from a point nearer than infinity (A, Fig. 24) are divergent when they reach the lens, and these will therefore be brought to a focus at a point (B) beyond the principal focus. It is evident that if the direction of the light be reversed, it will traverse the same path. The points A and B can therefore act reciprocally as object and image, and they are consequently called *conjugate foci*. This will hold good until the source of light reaches the principal focus itself, when the converse to the first condition will be established (Fig. 23). Here it is evident that rays issuing from the principal focus will emerge from the lens as parallel rays on the opposite side, and the image will be formed (theoretically) at infinity. If the luminous source is brought nearer to the lens, the rays will still be divergent when they issue from the opposite side, and consequently they will only meet " beyond infinity." In this case no real image is therefore formed, but a *virtual image* appears behind the luminous point on the same side of the lens (Fig. 25). Such an image cannot be cast upon a screen, but it can be seen by an observer on the opposite side of the lens.

The size and position of an image can be reconstructed pictorially in all these cases. To locate the position of the image of any point in an object it is sufficient to know the direction of any two rays, for where these two cross, there the image must be. We know that rays passing through the optical centre are not deviated, and that parallel rays pass through the principal focus. By drawing lines representing these rays the two typical figures represented in Figs. 26 and 27 are obtained. From them it is apparent that when the object is beyond the focal distance the image is inverted ; when it is nearer than the focal distance it is erect and magnified.

Digitized by Illinois College of Optometry Library

In practice, an object which is a considerable distance away, say 6 metres or more, may be considered to be at infinity, and the rays of light issuing from it may be taken as parallel. In this case a real image is formed by the lens

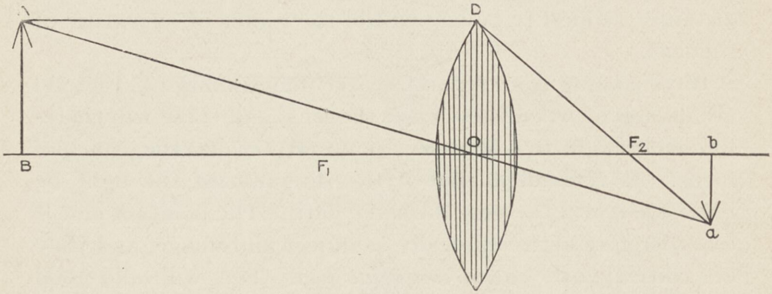


FIG. 26.—THE IMAGE FORMED BY A CONVEX LENS.—I.

The object (AB) is beyond the principal focus (F_1). The image (*ab*) is smaller, inverted, and also beyond the principal focus (F_2) on the other side of the lens. In this case the image is real.

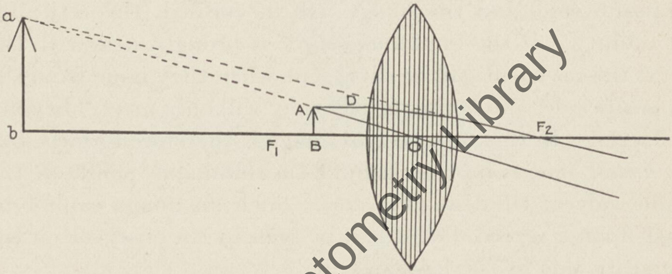


FIG. 27.—THE IMAGE FORMED BY A CONVEX LENS.—II.

The object (AB) is within the principal focus (F_1). The image (*ab*) is larger, erect, and behind the principal focus on the same side of the lens. In this case the image is virtual.

at the principal focus; it is very small and inverted. If the object is gradually brought nearer to the lens, the image recedes further and becomes larger, still remaining inverted, until, when the object reaches the principal focus, the image is infinitely far away and infinitely large, that is, nothing

Digitized by Illinois College of Optometry Library

determinate is seen. If the object is brought still closer to the lens, a virtual image can be appreciated by looking through the lens, and it will be found to be erect and the object will seem to be magnified.

Images formed by Concave Lenses.—The construction of

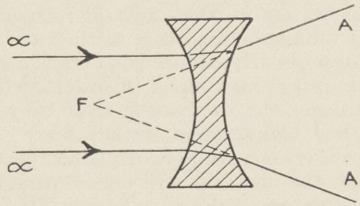


Fig. 28.—The Principal Focus of a Concave Lens.

When the incident rays are parallel, coming from infinity, they are diverged in the direction AA. They thus appear to come from a point F (the principal focus) on the other side of the lens.

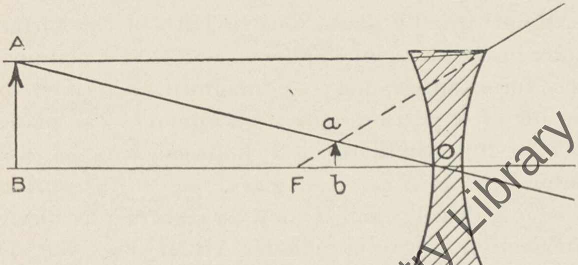


Fig. 29.—The Image Formed by a Concave Lens.

If AB is the object, the image *ab* is diminished, and erect, and, being formed on the same side of the lens as that from which the incident light comes, is virtual.

images formed by concave lenses depends on the application of the same principles as we have just considered. It is to be remembered that these diverge the rays of light, so that they never form a real image but always a virtual one. If the incident rays are parallel they will be diverged, but if they are produced backwards they will all cross the principal axis in a single point on the same side of the lens from which they come (Fig. 28): this is the principal focus. When the

Digitized by Illinois College of Optometry Library

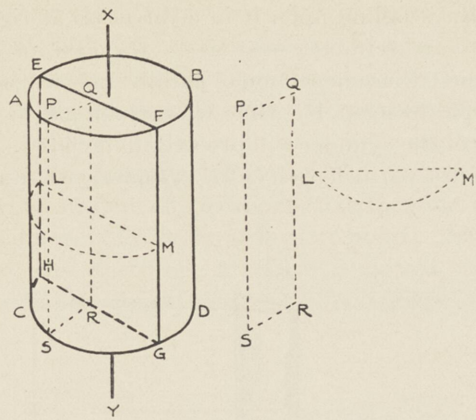
object is in any position, it will be found that the image is virtual, erect, and smaller than the object (Fig. 29).

The conception of a *virtual image* may be difficult to understand. Emerging from a concave lens the rays of light diverge further and further apart from each other, and, therefore, no point of union, or focus, can exist. We have noted, however, that in our mental experience we ignore the effect of refraction and project an object visually along the direction of the rays of light as they enter the eye. Consequently, an observer stationed at A (Fig. 28), receiving the diverging rays upon his eye, will neglect their refraction and will get the impression that they come from the point F, where they would meet if they were prolonged backwards. Although there is no image formed at this spot, or, indeed, at any point at all, the observer will believe that he does see the image of the object emitting the rays here. This apparent image is called *virtual.*

Refraction by Cylindrical Lenses.—We have seen that spherical lenses may be looked upon as composed of a refractive medium (usually glass), one or both of the surfaces of which are in the shape of a sphere ; and that a plano-spherical lens, for example, may be imagined as formed by the cutting off of a portion of a solid sphere by a plane (see Figs. 17 to 20). Similarly, a cylindrical lens, as used in ophthalmology, is a piece of glass, one of the surfaces of which is cylindrical ; and it may be regarded as formed by the intersection of a solid cylinder ABCD (Figs. 30 and 31), by a vertical plane EFGH in the line of the axis XY. It is thus curved in the horizontal meridian (LM), in which it acts as a spherical lens, and not in the vertical (PS), in which it acts as a plate with parallel sides ; this latter meridian is called the *axis.* Consequently it does not refract light falling perpendicularly upon it in the plane corresponding to the line of the axis. Since, as we have seen, a lens can be considered to act optically as a series of prisms, a cylinder can be considered as acting as if it were composed of many series of prisms arranged in superimposed rows.

The action of a *convex cylinder* is thus demonstrated in

Digitized by Illinois College of Optometry Library



FIGS. 30 AND 31.—THE FORMATION OF CYLINDRICAL LENSES.

FIG. 30.—The formation of a convex cylinder.

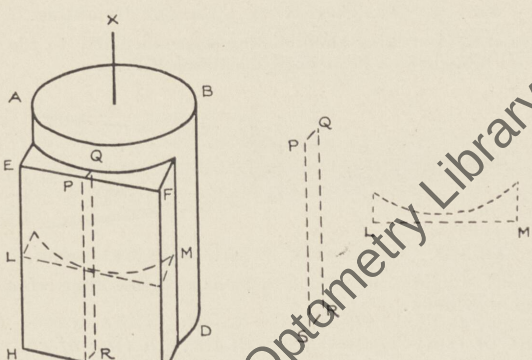


FIG. 31.—The formation of a concave cylinder.

ABCD is a solid cylinder whose axis is XY. It is cut by a plane EFGH which runs parallel to the axis, and the segment so delimited forms a cylinder. In the plane parallel to the axis XY the cylinder may be considered as a glass plate with parallel sides, PQRS. No refraction therefore occurs in this meridian. In the plane perpendicular to the axis, the cylinder may be considered as a lens LM. Refraction therefore occurs in this meridian.

Digitized by Illinois College of Optometry Library

Fig. 32. Rays falling upon it in a direction at right angles to the axis are refracted just as in the case of a convex spherical lens; thus one section of parallel rays will be brought to a principal focus at F′, while rays which are in the plane of the axis of the cylinder will proceed undeviated. This will occur down the entire length of the cylinder, and thus in place

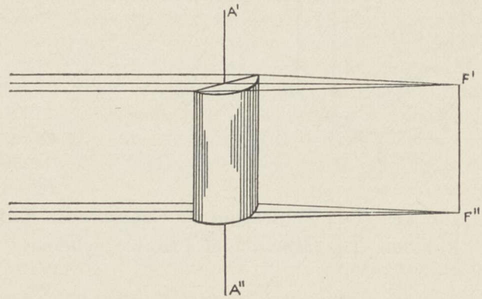


Fig. 32.—The Action of a Convex Cylinder.

Rays of light striking the cylinder perpendicularly to the axis A′A″ are brought to a focus in the focal line F′F″.

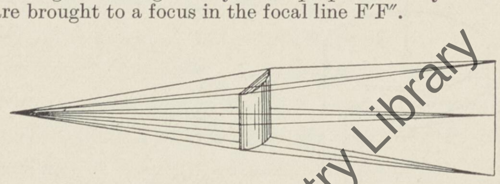


Fig. 33.—Refraction by a Convex Cylinder.

A point of light is brought to a focus as a line after refraction through a cylinder.

of a point of convergence we will have a *line of convergence* running in the same direction as the axis of the cylinder: in the figure, where the incident rays are parallel, each component segment of which the cylinder may be regarded as being composed, will have a principal focus at a corresponding point, and the line F′F″, which is made up of the sum of these individual foci, will be the *focal line*. Consequently, if a point of light is placed in front of the cylinder, no sharp image as a point can be formed on a screen, but a bright line

Digitized by Illinois College of Optometry Library

may be obtained (Fig. 33). Conversely in the case of a *concave cylinder*, rays falling perpendicular to the axis are diverged (Fig. 34) according to the same principles as we have discussed when considering the refractive properties of concave lenses.

Refraction by Astigmatic Lenses.—We have seen that in a spherical lens where all meridians have the same curvature, a definite image can be formed at a point; further, in a cylindrical lens where one meridian is curved and the one at right angles has no curvature at all, no image is formed at

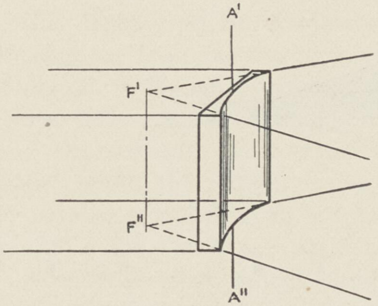


FIG. 34.—REFRACTION OF LIGHT BY A CONCAVE CYLINDER.

Rays of light striking the cylinder perpendicularly to the axis A′A″ are diverged, and appear to be brought to a virtual focal line F′F″.

a point but in a straight line. This therefore is the simplest form of an *astigmatic lens* (ἀ, privative; στίγμα, a point). We can now imagine a more complicated system where both meridians are curved but to a different degree; such an astigmatic surface is exemplified in the bowl of a spoon, the curve from side to side being greater than that from handle to tip. Where the two meridians in question are at right angles to each other, the condition is termed *regular astigmatism*. With this alone we need concern ourselves here.

The refractive properties of such a complicated lens may be gathered from a consideration of Fig. 35, where a lens is represented as having different curvatures in two meridians,

Digitized by Illinois College of Optometry Library

Carl F. Shepard Memorial Library
Illinois College of Optometry
3241 S. Michigan Ave.
Chicago, Ill. 60616

the vertical meridian (VV′) being more curved than the horizontal (HH′). It is evident that the more curved meridian will refract the rays incident upon it to a greater degree than the less curved, and consequently if parallel rays fall upon it, the vertical rays will come to a focus before the horizontal rays. There are thus two foci, the distance between which is termed the *focal interval.* No definite image is therefore ever formed as a point of light, but merely the blurred effect produced by a diffused bundle of rays.

The appearance of the bundle of rays at different points is

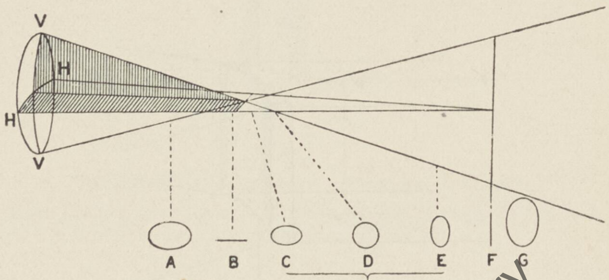


Fig. 35.—Refraction by an Astigmatic Lens; Sturm's Conoid.

VV, the vertical meridian of the refracting body, is more curved than HH, the horizontal meridian. A, B, C, D, E, F, G show different sections of the beam after refraction. At B the vertical rays are brought to a focus; at F the horizontal rays are brought to a focus. From B to F is the focal interval of Sturm. D shows the circle of least diffusion.

illustrated in the figure. At A, where the vertical rays are converging more rapidly than the horizontal, a section of the bundle will be in the form of a horizontal oval ellipse. At B, the vertical rays have now come to a focus while the horizontal ones are still converging; here the section will be a horizontal straight line. Beyond B the vertical rays are now diverging while the horizontal rays are still converging; at first the section (C) of the bundle will be a horizontal oval ellipse, but when the point D is reached, where the two opposing tendencies are equal and opposite,

Digitized by Illinois College of Optometry Library

the section becomes a circle : this is called the *circle of least diffusion*, where the least amount of distortion takes place. Beyond this point the divergence of the vertical rays becomes preponderating, and an ellipse is again formed, this time with its long axis vertical (E), until at F, where the horizontal rays come to a focus, the section will become a vertical straight line. Beyond this point, as at G, where both sets of rays are always diverging, the section will take the form of a gradually increasing vertical oval.

The Notation of Lenses.—The strength of a lens depends upon the degree to which it is able to refract light. As in the case of prisms, this depends on the refractive index of the substance composing the lens, the direction of the incident light, and the obliquity of the lens' surfaces. If we consider that the first two of these remain constant, there remains to be considered only the curvature of the surfaces : the greater the curvature, the greater the refractive power. We have seen that when parallel rays fall upon a spherical surface, they are brought to a focus at a point which is called the focal distance. This forms a convenient standard by which to measure the refractive power. A focal distance of 1 metre is taken as the unit, and a lens whose focal distance is 1 metre away is spoken of as having a refractive power of 1 *Dioptre* (1 D), a term introduced by Monoyer. Since a stronger lens has a greater refractive power, the focal distance will be shorter ; it therefore follows that a lens of a refractive power of 2 D will have a focal distance of 0·5 metre, while a lens of 0·5 D will have a focal distance of 2 metres. The strength in dioptres is therefore the reciprocal of the focal length expressed in metres.

A means of differentiation is required to indicate whether the light falling upon the lens is converged or diverged, and for this purpose the symbols + and — are employed. A convex lens which brings parallel light to a focus 1 metre away has therefore a refractive power of + 1 D, while a concave lens which in similar circumstances has a virtual

Digitized by Illinois College of Optometry Library

focus 1 metre on the same side as the incident light, has a refractive power of -1 D.

The Notation of Cylinders.—Exactly the same principles are applied to the case of cylinders. It is obvious that the effect of a cylinder upon a beam of light passing through it depends not only on the dioptric power of the cylinder, but also upon the position of its axis. Unfortunately there is some confusion as to the method which should be adopted in indicating the direction of the axis. The notation which will be adopted throughout this book will be the Standard Notation (or

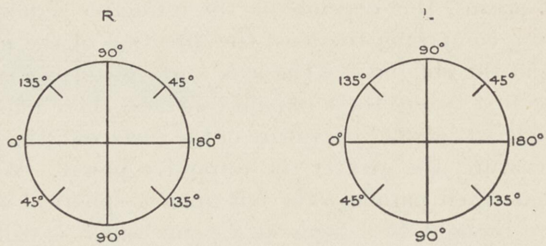


Fig. 36.—The Standard Notation of Lenses.

T.A.B.O.), as is illustrated in Fig. 36. In this system a similar notation is used for each eye: the observer is facing the patient, the zero is at the observer's left, and the scale is read below the horizontal with 90° at the bottom and 180° at the right side.

This notation was adopted by the Optical Society in 1904; a representative committee in Germany (Technischer Ausschuss für Brillenoptik—whence the Continental name T.A.B.O.) confirmed it in 1917; and the Council of British Ophthalmologists endorsed it in 1921. It is the notation adopted by every mathematical science, and in which all optical and mathematical instruments are graduated. It is the standard notation of all opticians in all countries, and into it all surgeon's prescriptions are translated by them before being sent to the workshop.

Every other possible system of nomenclature has from time to time been suggested and used. The two most frequently employed are the "International" (proposed by the International Congress at Naples in 1909), where zero starts on the nasal side of each eye,

Digitized by Illinois College of Optometry Library

and one wherein the angles are confined to right-angles, the direction being designated by an oblique stroke or by the phrases "down and in" and "down and out." Thus the angle 45° would be 45° ⁄ or "down and out" in the right eye, and 45° ⁄ or "down and in" in the left, and the angle 135° would be 45° ∖ or "down and in" in the right and 45° ∖ or "down and out" in the left. Were the standard notation universally adopted by ophthalmologists in writing prescriptions, the simple statement of the angle would be enough; but in the present state of indefiniteness it is as well to indicate the direction by an oblique stroke or an arrow, or preferably upon a diagram as Fig. 36.

The Detection and Measurement of Lenses.—*Spherical Lenses.*—In order to find out the nature and strength of a lens it is necessary to discover the position of its principal focus. As

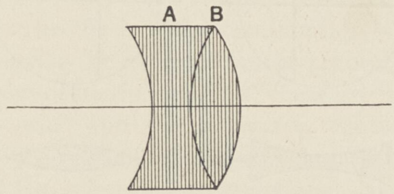


Fig. 37.—The Neutralization of Lenses.

Two lenses, A and B, of equal and opposite power, when placed in contact act as a plate with parallel sides.

we found in the case of prisms, however, it is much easier in practice to examine the image formed by the lens, and then to neutralise its effect by superimposing upon it a series of lenses of known strength in succession until one is obtained which is equal and opposite; in this case the image looked at through the combination will be of normal size and will not be displaced, but will appear as if looked at merely through a glass plate with parallel sides. The effect is seen in Fig. 37.

Thus if a convex lens is held up before the eye and a distant object is regarded through it, when the lens is moved a little from side to side, the image is seen to move in the opposite direction (Fig. 38). This reverse movement is due to the fact that the image formed by such a lens is inverted. With a concave lens, on the other hand, the image is erect, and

Digitized by Illinois College of Optometry Library

therefore moves in the same direction. From the direction of this movement we can tell at once the nature of the lens with which we are dealing. A lens of known refractive power and of the opposite kind is now placed in apposition to the first, and when the combination is moved, the displacement is noted; by a process of trial and error a combination is found which gives no displacement at all, and the strength

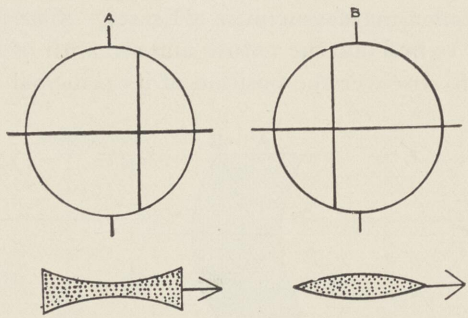


Fig. 38.—The Measurement of the Strength of Lenses.

A straight line is viewed through the lens, and the latter is moved in the direction of the arrow. In the case of a concave lens (A) the line appears to be displaced in the direction of movement. In a convex lens (B) the line appears to be displaced in the opposite direction.

of this lens is equal and opposite to that of the unknown lens.

Cylindrical Lenses.—By a similar method the presence of a cylinder may be detected. When such a lens is moved in front of the eye, an object looked at through it appears to be unequally displaced in different directions. When the cylinder is moved in the line of its axis, since there is no refraction in this plane, no displacement is produced, but when the cylinder is moved in any other plane, a gradually increasing degree of displacement is evident, which reaches its maximum when the plane at right angles to the first is reached. This gives us the direction of the axis of the cylinder.

Digitized by Illinois College of Optometry Library

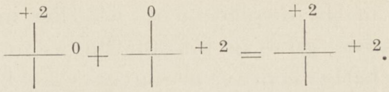
The direction of the displacement, whether in the same or the opposite sense, gives us information as to the nature of the cylinder, whether concave or convex ; and by neutralising the displacement by combining it with another cylinder of the opposite kind whose refractive power is already known, we can determine its strength. It is important to remember that in such a test the lenses should be held closely together and their optical centres should be in contact.

Optical Systems

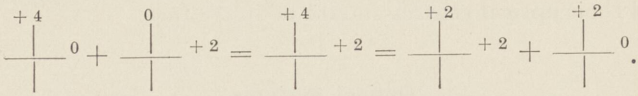
Refraction by Combinations of Lenses.—We have already demonstrated that when two lenses are placed in apposition to one another the effect of the combination is additive (see Fig. 37). This may be expressed more accurately by saying that in a system of lenses, provided these are infinitely thin, are infinitely near, and are accurately centred, the total refracting power of the system is equal to the algebraic summation of the refracting power of each component lens. Thus if a + 2 D and a + 2 D lens are combined in this way, the resulting power will be + 4 D ; if a + 2 D be combined with a — 2 D, no refraction at all will take place ; if a + 2 D be combined with a — 3 D lens, the combination will have a refracting power of — 1 D ; and so on.

A similar result will be obtained by combining cylindrical lenses. If they are in contact with their axes parallel, their combined power will be the sum of the power of each. If, however, they are held with their axes at right angles, there will be two focal lines perpendicular to one another, and since all rays must pass through both of these, they must meet at the point where these lines intersect. If the component lenses are of the same strength the combination thus acts as a spherical lens, whose refracting power is equal to the refracting power of the cylinders. Thus a + 2 D cyl. axis vertical combined with a + 2 D cyl. axis horizontal will combine to form a + 2 D sphere, which may be represented thus :

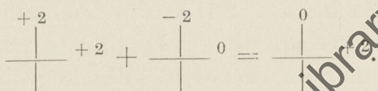
Digitized by Illinois College of Optometry Library



A + 4 D cyl. axis vertical combined with a + 2 D cyl. axis horizontal will in the same way act as a + 2 D sphere with the addition of a + 2 D cyl. axis vertical ; the combination is readily understood when written thus :



In the same way, combinations of spheres and cylinders are additive. When the two are of the same sign the matter is simple ; when they are of opposite sign the same principles hold although their application may appear superficially to be somewhat confusing. Thus if a + 2 D sphere is combined with a — 2 D cyl. axis vertical, the two curvatures in the vertical meridian will neutralise each other, leaving those elements of the sphere the curvatures of which are horizontal to act as a horizontal cylinder. Thus :



These simple relations hold when the lenses which compose

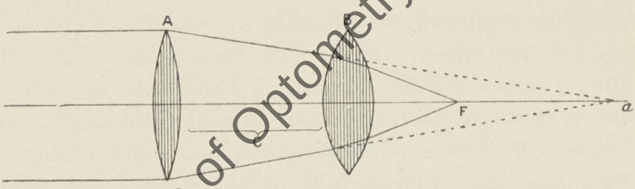


Fig. 39.—Refraction by a System of Lenses.

If the system consists of two lenses, A and B, separated by a distance C, the image after refraction by the first lens would be formed at *a*; but on meeting B, the rays are further converged, and brought to a final focus at F.

the system are so thin and so close together that their thicknesses and their distances apart can be neglected. Where

Digitized by Illinois College of Optometry Library

this cannot be done, however, the determination of the nature and the position of the resultant image becomes more complicated ; it involves the construction of the image formed by the first element in the system, its consideration as the object presented to the second element and the construction of the image by this, and so on through all the component parts of the system (Fig. 39). In a complex system this would be very tedious ; but, fortunately, the matter has been much simplified in its mathematical treatment by Gauss and Listing. From their calculations we can construct the image formed by any lens system, the elements of which are centred in the same optic axis, provided we know the relative position of three pairs of *cardinal points*, which are usually easily determined.

These cardinal points will be evident from the construction of Fig. 40.

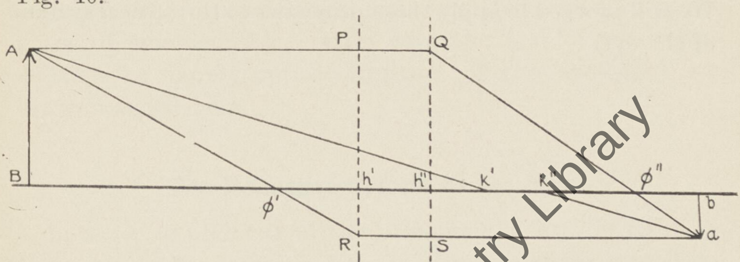


Fig. 40.—The Cardinal Points of a Compound Homocentric System.

AB, the object ; *ab*, the image ; Bb, the line upon which the system is centred ϕ' and ϕ'' are the two principal foci ; h' and h'', the two principal points ; k' and k'', the two nodal points ; PR and QS are the two principal planes.

(1) Two *principal foci* (ϕ' and ϕ''), which correspond in the complex system to the two principal foci of a simple lens (see Fig. 23). The first (ϕ') is therefore the point on the principal axis through which a ray must pass in order that it will emerge from the system as a parallel ray ; the second (ϕ'') is the point at which parallel rays entering the system will be brought to a focus. Thus if an object is situated at the first its image will be at infinity : if an object is at infinity, its image will be at the second.

(2) Two *principal points* (h' and h'') which deal with rays that are not necessarily parallel. They therefore correspond to the

Digitized by Illinois College of Optometry Library

conjugate foci in a simple lens (see Fig. 24). They are so disposed on the principal axis that when an object is placed at one, its image will be at the other. The two planes passing through the two principal points (h' and h'') are called the *principal planes*.

(3) Two *nodal points* (k' and k''), which correspond to the single optical centre of a simple lens. Consequently (as will be seen from Fig. 22), an incident ray directed to the first nodal point (k') will emerge from the system in the same direction along a line which comes from the second nodal point (k'').

From the points of intersection of the rays passing through these points, the image (ab) of an object (AB) can be constructed. The ray AQ, entering parallel to the axis, will run in the direction Qϕ'' The ray AR, running through ϕ', will continue parallel to the axis. The ray Ak' will leave the system as ka''. The intersection of these three lines at a gives the position of the image of A.

Knowing these cardinal points and their relationships, we can treat a complicated optical system theoretically as if it were composed of a single refracting medium subject to the comparatively simple laws with which we have dealt. We will proceed to apply these principles to the optical system of the eye.

Digitized by Illinois College of Optometry Library

CHAPTER IV

THE REFRACTION OF THE EYE

THE eye may be looked upon as an optical instrument designed to focus rays of light upon the retina by means of its refracting system in order that a clearly-defined image may be formed there. When the light falls upon the retina the energy which it represents sets in motion complex physico-chemical changes of whose intimate nature we know little ; by these it is transformed into neuro-physiological processes, which, being transmitted to the brain, are interpreted psychologically as perceptual images and correlated with the experiences of consciousness. It is with the first of these processes—the purely optical function of the eye—that we are concerned here.

The Refractive System of the Eye

In order to understand the behaviour of rays of light on their way to the retina and the mechanism of the formation of an image there, it is necessary to study the various refractive elements in their path. The structures which are met with in their passage through the eye are seen in Fig. 41. They are : the anterior surface of the cornea, the substance of the cornea, the posterior surface of the cornea, the aqueous humour, the anterior surface of the lens, the substance of the lens (which, as we shall see, is decidedly complicated), the posterior surface of the lens, and the vitreous humour.

This, however, may be considerably simplified. For our purposes it may be taken that the anterior and posterior surfaces of the cornea are parallel ; consequently, for optical

Digitized by Illinois College of Optometry Library

purposes, this tissue may be regarded as a plate allowing rays to pass through it without any deviation apart from a slight lateral displacement (Fig. 4). The substance of the cornea may thus be neglected in practice, and its two surfaces may be considered as one. In addition, the refractive indices of the aqueous and vitreous humour are practically the same (1·33), so that these two may be considered as one medium. The apparently complex system thus

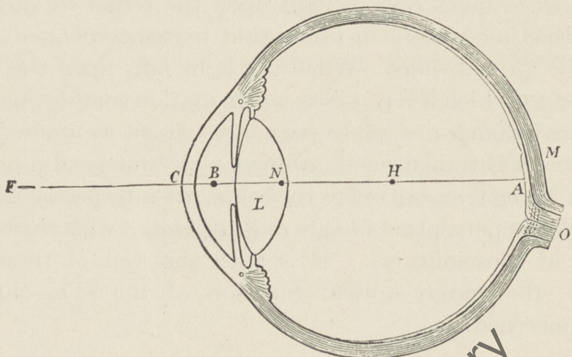


Fig. 41.—The Eye.

C, the cornea. B, in the anterior chamber, filled with aqueous. L, the lens. H, in the vitreous. M, the macula. O, the optic nerve. FA, the optic axis, meeting the retina at A. N, the nodal point. H, the centre of rotation.

resolves itself into one with two elements only: the surface of the cornea placed between the air and the medium formed by the aqueous and vitreous humours, and the lens. Each of these two components acts as a convex lens, the one reinforcing the action of the other, and the combination of the two provides a system with a remarkably strong refractive power, thus enabling the eye to act efficiently, and yet at the same time to remain manageably short and compact.

Refraction at the Corneal Surface.—By far the greater portion of the total refraction of the eye is effected at the

Digitized by Illinois College of Optometry Library

corneal surface. When rays of light fall upon it they are converged by an amount determined, firstly, by the difference in refractive index between the air and (in the simplified scheme we have decided to employ) the aqueous humour, and secondly, by its curvature. In point of fact, the cornea is not spherical, since the peripheral parts are substantially flatter than the central area, but inasmuch as the central part only is used for vision, it may be considered as being a sphere whose radius of curvature is about 8 mm.[1]

The refractive index of the aqueous humour is measured by a refractometer; it is found to be 1·33, while that of the air is 1. The curvature of the cornea cannot be measured directly in the living eye, and in the dead eye the conditions are altered; consequently an indirect optical method is employed, which, although of considerable interest, cannot be described here in detail. It depends on the fact that since the surface of the cornea acts as a convex mirror, the size of the image produced by such a mirror varies with its curvature; the greater the curvature of the mirror, the smaller the image. A luminous body is therefore held up before the cornea, and the image as seen therein is measured; hence, knowing the size of the object and its distance from the eye, the radius of curvature of the cornea can be deduced. The accurate measurement of these images presents the further difficulty that it is impossible to immobilise the living eye completely while the images are under observation. This has been overcome by the use of a device adopted originally by Thomas Young from astronomy, and perfected in the Helmholtz ophthalmometer. The image is doubled by refraction through two rotating glass plates, which are then adjusted so that the lower edge of one image coincides with the upper edge of the other; if the eye moves during the process, both images move together, and therefore difficulties in adjustment are avoided. From the amount of rotation of the glass plates necessary just to double the image, its size can be calculated.

The refractive power of the cornea may be taken as varying from + 40 to + 45 D., while that of the lens is only about

[1] These measurements have been most thoroughly investigated by Tscherning (1920) and Gullstrand (1924). Their values are:—

	Gullstrand.	Tscherning.
Cornea radius. ant. surface	7·7 mm.	7·98 mm.
,, ,, post. surface	6·8 mm.	6·22 mm.

Digitized by Illinois College of Optometry Library

half of this. The preponderance of the influence of the cornea is largely due to the greater difference in refractive index between the air and the aqueous humour compared with that between the aqueous and the lens. Consequently, when the eye is immersed in water (which has practically the same refractive index as the aqueous humour), vision becomes very blurred. Fishes overcome this difficulty by having a small, almost spherical, lens of great converging

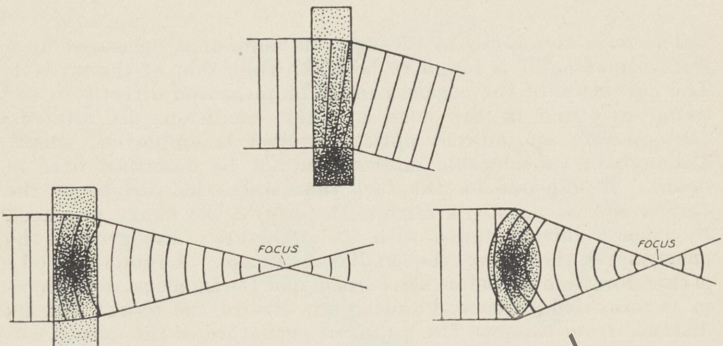


Fig. 42.—Refraction of the Lens.

The first illustration shows how a plate of glass, if of unequal optical density, will refract light. If the point of greatest density be in the centre, a plate with parallel sides will act as a converging lens, as is seen in the second figure. If, in addition, the sides are given a curvature, as in the third figure, the double influences of the refracting surfaces and the density will greatly augment the converging power.

power, which is able to take the principal part in the refraction of the light. Divers suffer from the same disability as fish, and for this reason a special type of goggles has been devised for them wherein the necessary difference in refractivity has been attained by combining two meniscus glass lenses so that they enclose between them a biconcave " lens " of air.

Refraction by the Lens.—The refractive properties of the lens are complicated by the fact that it is not a homogeneous structure. On the contrary, it is made up of

Digitized by Illinois College of Optometry Library

several layers, the central nuclear ones having a higher index of refraction than the peripheral cortical ones. It will be readily seen from Fig. 42 that this progressive increase in optical density will greatly augment its converging power, for even a plate with parallel sides, if constituted in this way, will act as a lens of considerable strength. In addition to this difference in refractivity, the converging effect is further augmented by the fact that the various layers are not strictly concentric. The curvature of the outer ones is less than that of the inner, so that the central nucleus in comparison with the outer part of the cortex is approxi-

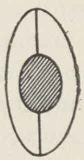


FIG. 43.—THE STRUCTURE OF THE LENS.

The central nucleus is nearly spherical, and the cortex may be considered as two encapsulating menisci. The greater curvature of the inner layers increases their refractive power.

mately spherical (Fig. 43). Thus each successive layer, with its higher optical density and greater curvature, acts as an increasingly powerful lens.

The curvatures of the surfaces of the lens are unequal, the anterior being flatter than the posterior. They may be measured by a method similar to that employed in the case of the cornea, when it is found that the radius of curvature of the anterior surface is about 10 mm., while that of the posterior is about 6 mm.[1] The refractive index of the substance of the lens near the periphery is 1·386, while that of the nucleus is about 1·41, the mean value being approximately 1·39. Owing to the complexity of its architecture, however, the entire lens has a refractive power higher than

[1] Exact measurements are :—

	Gullstrand.	Tscherning.
Lens radius, ant. surface	10·0 mm.	10·2 mm.
,, ,, post. surface	6·0 mm.	6·17 mm.

Digitized by Illinois College of Optometry Library

these figures indicate, and would correspond to a uniform refractive index of 1·42 if the lens were homogeneous. Its total strength is thus equal to that of a lens of about + 23 D.

It is true that when the lens is extracted, normal vision may be obtained with a correcting lens of + 10 D placed in front of the eye. But if the glass lens were to be placed inside the eye in the exact position occupied by the crystalline lens in life, a strength of + 23 D would be required.

The comparatively great refractive strength of the lens has a biological importance other than the ability to converge the rays of light effectively upon the retina. Its structure diminishes the optical errors of spherical and chromatic aberration, it reduces the amount of scattered light within the eye-ball, and since the power of varying the refraction (that is, the accommodation) depends upon the refractivity of the lens, the peculiar structure of this tissue enables it to exercise nearly double the range it would otherwise have. These matters will be dealt with subsequently.

The Reduced Eye.—We have seen in the previous chapter that the refractive properties of a complex optical system can be reduced to the basis of a simple one by the application of the principles of the Theorem of Gauss, provided the components of which it is formed are centred on the same optical axis. The eye forms, approximately, such a homocentric system. We have studied the properties of the two elements comprising this system, and Tscherning and Gullstrand have determined their relative distances apart on the optic axis. The measurements of the two are in substantial agreement. They show, however, some discrepancies; and since Tscherning's measurements were based on the observation of one eye (that of a tall man), we will rely on the calculations of Gullstrand, which are more representative. These measurements should certainly replace the older and less accurate ones of Helmholtz. Gullstrand found that the distance from the anterior surface of the cornea to the anterior surface of the lens was 3·6 mm., while that from the

Digitized by Illinois College of Optometry Library

anterior to the posterior surface of the lens was also 3·6 mm.[1] We have now all the data we require in order to consider the eye as a whole as an optical apparatus.

Working upon these data, and applying to them the rules of Gauss, we can calculate the cardinal points of the optical system (Fig. 44). It is found, however, that when we do so, the two principal points and the two nodal points are very close together, so close, indeed, that no great inaccuracy will

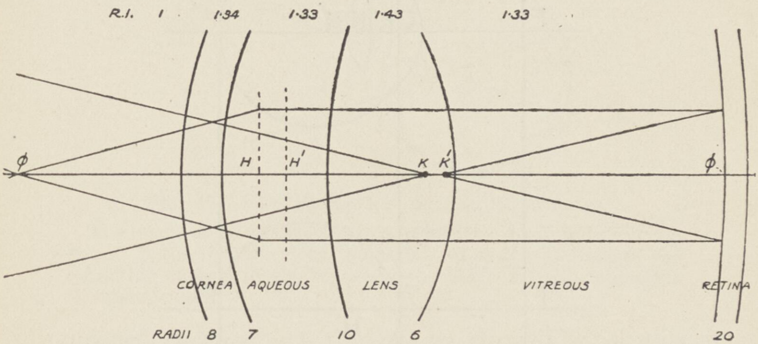


FIG. 44.—THE CARDINAL POINTS OF THE EYE.

ϕ, The anterior principal focus, 15·7 mm. in front of the cornea.
ϕ'', The posterior principal focus, 24·13 mm. behind the cornea—that is, upon the retina.
H, H′, the principal points, in the anterior chamber.
K, K′, the nodal points, in the posterior part of the lens.

arise if we substitute for each pair an intermediate point and consider them as one. Without introducing any appreciable error, we can thus treat the optical system of the eye as if it were a single ideal refracting surface. This concept of a *reduced eye*, or *schematic eye* was introduced by Donders, and it has the following properties :

> It is an ideal spherical surface whose radius of curvature is 5·73 mm. which separates two media of refractive indices 1 and 1·336. It lies about 1·35 mm. behind the anterior surface of the cornea, that is, in the anterior chamber. Its nodal point (optical centre) is therefore

[1] Tscherning's measurements were 3·54 mm. and 4·06 mm. respectively.

Digitized by Illinois College of Optometry Library

7·08 mm. behind the anterior corneal surface, that is, in the posterior part of the lens. Its anterior focal distance is 17·05 mm. (or 15·7 mm. in front of the cornea), and its posterior focal distance is 22·78 mm. (or 24·13 mm.

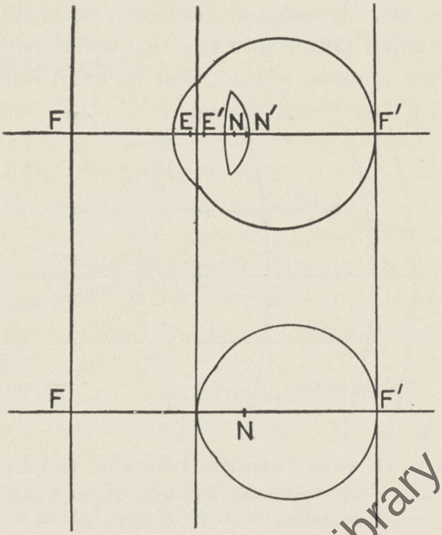


Fig. 45.—The Reduced Eye.

The upper figure represents the normal eye, with the two focal points at F and F′, the two principal points at E and E′, and the two nodal points at N and N′. The reduced eye, drawn in scale to correspond, is shown below, with the two principal foci at F and F′, the single refracting surface corresponding to the mean of E and E′, and the nodal point at N, corresponding to the mean of N and N′.

behind the anterior surface of the cornea), that is, in an average eye, upon the retina.

The formation of this reduced eye is shown in Fig. 45. With it alone we will deal, and on its basis it is a simple matter to construct the nature of the images thrown upon the retina.

The Formation of Retinal Images.—The construction of a retinal image will be gathered from Fig. 46. Since the nodal point (N) acts as the optical centre of the reduced optical

Digitized by Illinois College of Optometry Library

system, rays which pass through it will not be appreciably refracted. If, therefore, an object (AB) is placed in front of the eye, its image (*ab*) may be constructed by drawing straight lines from the extremities of the object through the nodal point and producing them until they reach the retina. It is evident that the image thus obtained is inverted and

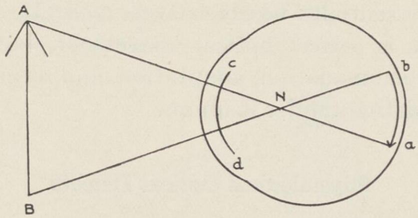


Fig. 46.—The Formation of Retinal Images.

The image *ab* of an object AB is formed by drawing lines from A and B through the nodal point N. *cd* is the position of the refracting surface in the reduced eye. ANB or *a*N*b* represents the visual angle.

diminished, just as are the images formed by a convex lens; it is re-inverted psychologically in the cerebral cortex.

These two lines will enclose an angle at the nodal point; this, the angle ANB, is known as the *visual angle*, and is defined as the angle subtended by the object at the nodal point. It is, of course, equal to the angle *a*N*b*, which is subtended by the retinal image at the nodal point.

The Optical Defects of the Eye

The accuracy with which any optical apparatus is able to form a clearly defined image is called its *resolving power*, which is thus an index of the efficiency of the system. Every lens system has inherent defects, in all of which the eye participates to a marked extent. So marked, indeed, are these aberrations that Helmholtz is reported to have said in very forcible language that if he got such an instrument from an optician he would return it with contumely to its

Digitized by Illinois College of Optometry Library

maker. The important thing to remember, however, is that although the eye does possess these defects it possesses them to so small a degree that, for functional purposes, their presence is immaterial; living organisms are never built on precisely applied mathematical laws, and any theoretical inaccuracies they may show in their configuration are more than counterbalanced by the adaptability and plasticity which their essentially flexible nature permits. The eye is by no means a perfect optical instrument, but its potentialities of accommodation, adaptation, and retinal definition and differentiation render it unique.

Physiological Optical Defects

Some of these defects are inherent in the "normal" eye, and are therefore physiological; others must be considered

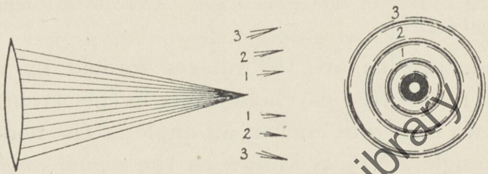


Fig. 47.—The Diffraction of Light.

Light brought to a focus does not come to a point, but gives rise to blurred disc of light surrounded by several dark and light bands. The effect, of course, in the figure is much exaggerated. (After Beck, Cantor Lectures, London, 1908.)

as abnormal. We will consider shortly those of the first class, and then examine the others in greater detail.

(1) **Diffraction of Light.**—When a wave of light travels through space, the sides of the wave tend to deviate: expressed in popular language, having no support they tend to fall away from the main body of the wave. This effect is especially marked in a narrow wave, such as one which has passed through a pupillary aperture. The image, therefore, produced by a parallel bundle of rays, after passing

Digitized by Illinois College of Optometry Library

through a converging lens, is not a mathematical point, as it theoretically ought to be, but a series of concentric rings of light with a bright spot at their centre : such an appearance is seen exaggerated diagrammatically in Fig. 47. In the eye with a pupil of 2 mm. diameter, the diameter of this spot is 0·01 mm., and this inherent property of light thus sets a limit to the definition of the retinal image no matter how perfect the optical system itself may be.

(2) **Chromatic Aberration.**—White light is composed of

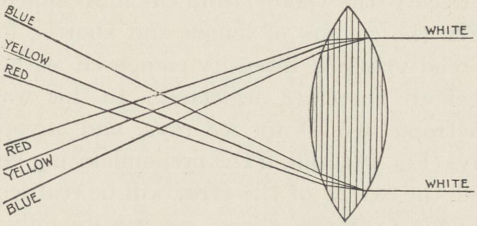


Fig. 48.—Chromatic Aberration.

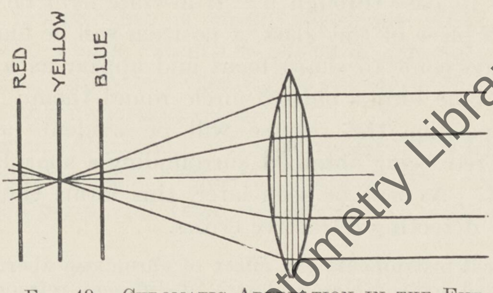


Fig. 49.—Chromatic Aberration in the Eye.

The dioptric system of the eye is represented by a simple lens. The yellow light is focused on the retina, and the eye is myopic for blue, and hypermetropic for red.

rays of different wave-length, which, when taken separately, form the various colours of the spectrum. As we would expect, the short waves are retarded most in passing through a refractive medium, and hence on their way through a lens they are more acutely bent than the longer ones, so that they come to a focus in front of them. The short blue and violet

Digitized by Illinois College of Optometry Library

rays therefore come to a focus in front of the long red rays. The effect of this phenomenon of the dispersion of light by a lens will be evident from Fig. 48. This to a certain extent reduces the definition of the retinal image, but the amount is small; it increases with the size of the pupil, and with a pupillary diameter of 2 mm., approximately 70 per cent. of the light falls on an area of 0·005 mm. diameter. Moreover, the effect is to a certain extent neutralised by the fact that the eye is normally focused so that the rays of greatest intensity (the yellow) form the most sharply-defined image, while the colours of longer and shorter focus form circles of relatively low intensity compared with this, and their images are therefore neglected. In this way the eye is hypermetropic 0·5 D for red rays, and myopic 1·5 D for blue rays (Fig. 49), and, if the preponderating yellow light be excluded, the extent of the error will be realised. Cobalt blue glass, for example, allows practically only red and blue rays to pass through it. If a white light be regarded through a piece of this glass, a position will be found when the red rays come to sharp focus and appear as a red spot while the blue form a blurred circle round them; while in another position the reverse will be evident—a blurred circle of red being obtained surrounding a sharply-defined blue spot. As will be seen later, this forms the basis of a test for detecting refractive errors.

In optical instruments the effect of chromatic aberration can be abolished by combining glasses of different refractive index and different dispersions to form a compound lens. Thus flint glass gives a dispersion nearly double that of crown glass, and its index of refraction is 1·7, while that of crown glass is 1·5; hence, if we combine a convex lens of crown glass with a concave lens of half the strength composed of flint glass, the dispersion will be neutralised, while a considerable part of the refractivity of the crown glass will still remain. Such a combination forms an *achromatic lens*.

The story of chromatic aberration is interesting, even among the many stories associated with the development of optical science, in showing how useful results may arise from wrong hypotheses. Newton concluded that dispersion was always

Digitized by Illinois College of Optometry Library

proportional to refractivity, and thus imagined that the realisation of an achromatic system was impossible; he therefore discarded his work on astronomical telescopes, in which the images are formed by refraction, and turned his attention to catoptric telescopes, which make use of reflected images. Euler, however, thinking that the eye was achromatic, stimulated an optician, Dolland, to construct achromatic lenses. Later Wollaston, finding under controlled experimental conditions that the red end of the spectrum was sharply focused by the eye while the blue end was not, demonstrated that the eye was subject to chromatic aberration.

(3) **Chromatic Difference of Magnification.**—Owing to this unequal refraction of light rays, not only are images formed at different distances from the cornea, but when the object is a little to the side of the optical axis, the images produced by the short rays will be smaller than those formed by the long rays. We shall see that the fovea, which is the point of the retina with the greatest acuity of vision, is a little to the side of the optical axis, and consequently all images falling upon it must suffer from this error. This, however, has a beneficial rather than a disadvantageous effect, for it neutralises to a large extent the effects of chromatic aberration; indeed, it may be a teleological reason for the eccentric position of this important region.

(4) **Spherical Aberration.**—The periphery of a lens has a higher refracting power than the central parts, and consequently the peripheral rays are brought to a focus more

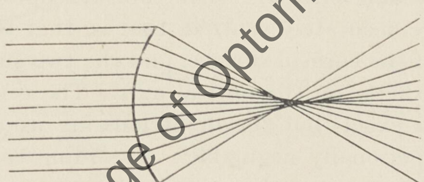


Fig. 50.—Spherical Aberration.

quickly than the central ones. Definition again suffers in this way, for the focus is not a point but a line, as is seen in Fig. 50. The phenomenon, however, is little evident in the

Digitized by Illinois College of Optometry Library

eye unless the pupil is widely dilated, for in ordinary circumstances the peripheral rays are cut off by the iris. In addition, an exactly opposite and neutralising effect is produced by the fact which we have already noted, that the central portions of the lens have a greater density and are arranged in layers of greater curvature than the peripheral ones, thus tending to level up the general effect. Even when the pupil is dilated the error is to some extent remedied by the peculiar curvature of the cornea, which we have seen to be flatter at the periphery than at the centre. It may be taken, then, that the effects of spherical aberration are altogether negligible compared with those of diffraction and chromatic aberration.

In making lenses this error can be eliminated by grinding them so that their curvature gradually decreases from the centre to the periphery. The error is diminished by making the curvature of the anterior surface greater than that of the posterior; it is for this reason that the objectives of opera glasses are bulged in front. The best forms are the so-called *periscopic* and *meniscus lenses*, where the radius of curvature of the posterior surface is greater than that of the anterior surface (see p. 346). Such lenses are called *aplanatic*. In practice, by combining lenses of flint and crown glass of appropriate power in a suitable way, an achromatic and aplanatic combination can be made at the same time, thus eliminating both chromatic and spherical aberration.

(5) **Decentring.**—The formation of an ideal image would demand that the refractive surfaces in the optical system of the eye were accurately centred, that is, that the centres of curvature of the corneal surface, and the two surfaces of the lens were exactly on the optical axis. The centring of the eye is never exact, but the deviations are usually so small as to be functionally negligible. According to Tscherning, the usual defect is that the centre of curvature of the cornea is situated (as much as 0·25 mm.) below the axis of the lens. It is as if an optician in the making of an opera glass had placed one of the lenses a little below the axis of the instrument by a defect of workmanship.

Digitized by Illinois College of Optometry Library

We have noted that the fovea is not usually situated on the optic axis, but is placed about 1·25 mm. downwards to its temporal side. Since this part of the retina is used for distinct vision, we do not look directly along the optic axis when we look at an object, but along a line joining the object (or the *fixation point*) with the

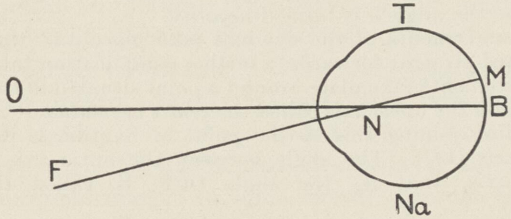


Fig. 51.—The Angle Alpha.

T, temporal side ; Na, nasal side ; OB, optical axis ; FM, visual axis, connecting the point of fixation (F) to the macula (M). The two cut at the nodal point, N. The angle ONF is the angle α.

fovea and passing through the nodal point (Fig. 51). This line (FNM) is called the *visual axis.* Sometimes the optic axis does cut the fovea, in which case the optic axis corresponds with the visual axis ; usually it does not, but the visual axis cuts the

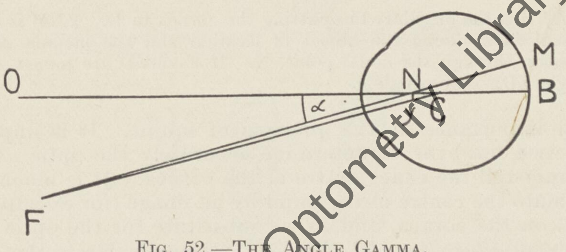


Fig. 52.—The Angle Gamma.

OB, the optical axis ; FM, the visual axis, the two cutting at the nodal point, N. C, the centre of rotation, and FC, the fixation axis. The angle OCF is the angle γ.

cornea slightly up and to the nasal side of its centre, so that when the eye looks directly forward at an object, the optic axis is directed somewhat down and out. The angle formed at the nodal point between these two axes, that is, the angle ONF, is called the *angle alpha* (α) ; its average size is 5°. It is as though, instead of looking directly along the central axis of an opera glass, we tilted it very slightly ; the amount of tilt would then represent

Digitized by Illinois College of Optometry Library

the angle α. We have seen that this deviation seems to have a teleological significance since it tends to correct chromatic aberration at the fovea.

When the visual axis cuts the cornea, as it usually does, on the nasal side of the optic axis, the angle α is designated *positive ;* when the two axes coincide the angle is *nil ;* sometimes the visual axis cuts the cornea on the temporal side of the optic axis, in which case the angle α is termed *negative.*

When movements of the eye-ball take place and the gaze is not directed straight forwards, a further complication takes place. These movements take place around a point situated in the middle of the eye on the optic axis called the *centre of rotation* (C, Fig. 52), and the line joining this to the point of fixation is called the *fixation axis* (FC). The angle between the optic axis and the fixation axis, that is, the angle OCF, is called the *angle gamma* (γ).

We shall see later that the measurement of these angles is of

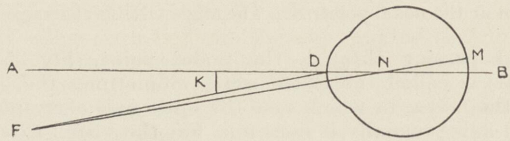


FIG. 53.—THE ANGLE KAPPA.

ANB is the pupillary line cutting the cornea in D. FNM is the visual axis joining the object of fixation and the macula, and passing through the nodal point, N. If F and D are joined, the angle ADF is the angle κ.

clinical importance in the question of squint. It is impossible in practice, however, to determine accurately the optic axis, for we cannot tell the exact centre of the cornea. It is much easier to estimate the centre of the pupil by an image (for example, of a candle) on the cornea, and so we substitute for the optic axis a line, the *pupillary line* (AN, Fig. 53) perpendicular to the cornea and passing through this point. The angle formed between this line and the visual axis is called the *angle kappa* (κ). The centre of the pupil is somewhat to the nasal side of the centre of the cornea, but for clinical purposes the optic axis and the pupillary line may be taken as coincident, and the angle formed at the cornea (ADF) may be considered equal to that subtended at the nodal point (ANF).

(6) **Peripheral Aberrations.**—Several optical considerations combine to make the images formed in the peripheral parts

Digitized by Illinois College of Optometry Library

of the retina less clearly defined than those in the central area. Some of the most important of these are the phenomena known as *comma, radial astigmatism* and *distortion of the image;* but since most of them are to a large extent neutralised by the peculiar shape of the eye, they need not be discussed in detail. The curve of the retina has a very important effect on the efficiency of peripheral vision, and calculation shows that a very close approximation to the ideal optical conditions has been adopted. But although the ideal is not reached, the functional efficiency of the eye is greatly augmented by sacrificing the definition of the marginal images to some extent in order to get the best possible conditions for the central ones.

Circles of Diffusion.—These aberrations may appear unimportant inasmuch as they occur normally and do not obtrude themselves into our consciousness in every-day life, but we shall find that they require practical consideration

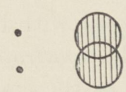


Fig. 54.—Circles of Diffusion: the Image of a Point is a Circle.

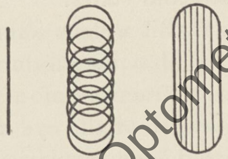


Fig. 55.—Circles of Diffusion: the Image of a Line is a Broad Band.

when we are dealing with the correction of errors of refraction, especially the larger ones, by artificial lenses. In the normal eye their combined result is that no clear image is formed as a point focus on the retina, but only as a circle of light which involves a certain amount of blurring. Such a circle is called a *circle of diffusion*, and its nature will be gathered from Fig. 54. It will be remembered that a line

Digitized by Illinois College of Optometry Library

may be considered as a number of points, and therefore its image may be construed as a number of such circles superimposed the one upon the other so as to overlap to a large extent: a narrow line therefore becomes converted into a broad band (Fig. 55). The smaller these circles are, the greater will be the efficiency of vision, and thus to obtain the *circle of least diffusion* is our object in the correction of pathological errors in the optical system of the eye.

Pathological Optical Defects

We have seen that in the theoretically perfect eye parallel rays of light are brought to a focus upon the retina; in the physiologically normal eye such rays converge here to form a circle of least diffusion. We shall see later that the focal length can be varied within limits by increasing the refractive power of the lens by an effort of the ciliary muscle in the mechanism known as accommodation; but when these ideal optical conditions occur with the eye in a state of rest the condition is termed *emmetropia* (ἐν, within; μέτρον, measure; ὤψ, the eye). In the emmetropic eye, therefore, the image of a distant object is formed without effort upon the layer of retinal rods and cones.

It would be strange if this were a common state of affairs. It must be remembered that its attainment depends on an exactitude to within a fraction of a millimetre of such measurements as the length of the eye and the shape of the cornea and the lens; and such regularity and conformity to type as optical perfection would necessitate, demands a mathematical accuracy which is nowhere realised in the constitution of living organisms. Emmetropia may be optically normal, but it is no more biologically normal than would be the universal attainment of a uniform height of five feet six inches. The opposite condition of *ametropia* (ἀ, privative; μέτρον, measure; ὤψ, the eye), when parallel rays of light are not focused exactly upon the retina with the eye in a

Digitized by Illinois College of Optometry Library

state of rest, is therefore much the more common. The frequency of its incidence, indeed, is not always realised: thus Clarke, on examining 2,500 individuals whose vision was normal after refractive correction, and who had no disease of the eyes, found only nine who were emmetropic. When the refractive condition of the two eyes is unequal, the condition is known as *anisometropia* (*ἀ*, privative; *ἴσος*, equal).

Ametropia may be of three main types: a principal focus may be formed by the refractive system of the eye, but instead of it being situated on the retina (as in emmetropia),

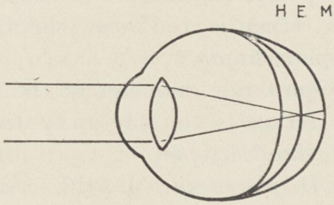


Fig. 56.—Emmetropia, Hypermetropia and Myopia.

In emmetropia (E), parallel rays of light are focused upon the retina. In hypermetropia (H), the eye is relatively too short; in myopia (M), it is too long.

it may be situated either behind it or in front of it. In the first case the eye is relatively too short, and the condition is then called *hypermetropia* (Fig. 56); in the second it is relatively too long, when the term *myopia* is used. Alternatively, the refractive system may not be concentric so that no single focus is formed, in which case *astigmatism* is present. In the first case, the incident rays may be converged before entering the eye by a convex lens so that the principal focus is moved forward to the retina; in the second a concave lens placed before the eye will diverge the incident rays so that the focus will be moved back to the retina; and in the third a cylindrical lens may neutralise the refractive anomaly and enable a focus to be formed.

Digitized by Illinois College of Optometry Library

Clarke gives the following frequencies of those conditions :—

2,500 individuals.	Same refraction in both eyes		657
	Emmetropia	9	
	Hypermetropia	63	
	Myopia	22	
	Astigmatism	563	
	Anisometropia		1,843
5,000 eyes (as above)	Emmetropia	56	
	Hypermetropia	425	
	Myopia	216	
	Astigmatism	4,303	

These refractive anomalies can obviously be caused by various conditions.

I. The Position of the Elements of the System.

(*a*) The antero-posterior diameter of the eye is too short, and the retina is too near the optical system : *Axial hypermetropia.*

(*b*) The antero-posterior diameter of the eye is too long and the retina is too far away from the optical system : *Axial myopia.*

(*c*) *Lenticular Displacement.*—If the crystalline lens is dislocated forwards, *myopia* will exist ; if backwards, *hypermetropia.*

II. Anomalies of the Refractive Surfaces.

(*a*) The curvature of the cornea or of the lens may be too small, giving a *curvature hypermetropia ;*

(*b*) or too great, giving a *curvature myopia ;*

(*c*) or be irregular, varying in different meridians, giving *astigmatism.*

In *hypermetropic astigmatism*, the curvatures of both axes are unequal and too small ; in *myopic astigmatism* they are both unequal and too great ; when the two conditions are combined so that one axis is hypermetropic and the other myopic, the condition is termed *mixed astigmatism.*

(i.) If the axes showing the greatest difference in curvature are at right angles, the condition is called *regular astigmatism.*

Digitized by Illinois College of Optometry Library

(ii.) If they are not so related, the astigmatism may be called *oblique*. (For terminology, see p. 124.)

(iii.) If no two axes are formed, but the surface is cone-shaped, the condition, if due to the cornea, is called *keratoconus*, if to the lens, *lenticonus*.

(iv.) If there is no symmetry about the refraction and different groups of rays form foci at different positions, as occurs in the cornea after corneal ulceration or in the lens in developing cataract, the astigmatism is called *irregular*.

III. Obliquity of the Elements of the System.

(*a*) *Lenticular Obliquity.*—If the lens is placed obliquely, or subluxated, astigmatism will result.

(*b*) *Retinal Obliquity.*—The posterior pole of the eye may be placed obliquely, as when it bulges backwards in a staphyloma in high myopia. If the summit of the staphyloma does not correspond with the fovea the rays do not fall upon this region perpendicularly. If the focus were a point this would be without effect, but since it is a diffusion circle of measurable diameter the obliquity will deform and increase it, thus diminishing visual acuity. This form of error is frequently overlooked.

IV. Anomalies of the Refractive Index.

(*a*) If the refractive index of the aqueous humour be too low, or of the vitreous humour be too high, there will be an *index hypermetropia*. This will be understood when it is remembered that the amount of refraction at the corneal surface depends largely on the difference in refractive index between air and the aqueous. If the refractive index of the aqeuous is low, that is, more nearly that of air, the refraction will be less. Similarly, when we consider the light travelling from the lens into the vitreous, if the refractive index of the vitreous be high, that is, more nearly that of the lens, the

Digitized by Illinois College of Optometry Library

refraction will again be less. Conversely if the index of refraction of the aqueous be too high or that of the vitreous too low, there will be an *index myopia*.

(*b*) If the refractive index of the lens as a whole were too low, there would be index hypermetropia, if too high there would be index myopia. If the index of the cortex increases relatively and approximates that of the nucleus, as it does normally in old age, the lens tends to act as a single refractive element, and consequently has less converging power than normal; the eye therefore becomes hypermetropic. Conversely, if the index of the nucleus increases, as frequently occurs in early cataract, myopia is produced. If the increase of the refractive index of the nucleus is very marked, a *false lenticonus* may be produced, wherein the central part of the pupil is myopic and the periphery hypermetropic. If the index of any part varies irregularly in different localities, as in developing cataract, an *index astigmatism* is produced.

V. Absence of an Element of the System.

Absence of the lens, a condition known as *aphakia*, produces hypermetropia.

The Size of the Pupil : Stenopaeic Apertures.—The beam of light within the eye takes the form of a cone, the base of which is formed by the pupillary aperture ; the smaller this aperture is, the smaller will be the section of the cone. In these circumstances the effects of diffraction will be smaller, and since the periphery of the lens is largely responsible for the errors of spherical and chromatic aberration, the errors which these introduce will be correspondingly reduced. The beneficial effect of a small pupil will be more evident where the apex of the cone does not fall upon the retina, as when a near object is looked at with the emmetropic eye, or in all cases in an ametropic eye. Thus when an object O (Fig. 57) is regarded and the pupil contracts from the size *aa* to

Digitized by Illinois College of Optometry Library

b, the diffusion circle formed by the image of O will be reduced from a_1a_1 to b_1, and will consequently have a less disturbing effect. If we suppose, for example, with the large pupil, aa, the converging pencil of rays covers an area in the macular region (a_1a_1) occupied by 100 cones, and if the pupil were contracted so that its radius were reduced to one-fifth of its original size, the area covered will be $\frac{1}{25}$ smaller (b_1), and only 4 cones will be involved. Theoretically, if the pupils were reduced to a point one ray only would enter, one cone would be stimulated, and a clear image would be formed in all cases, no matter what the

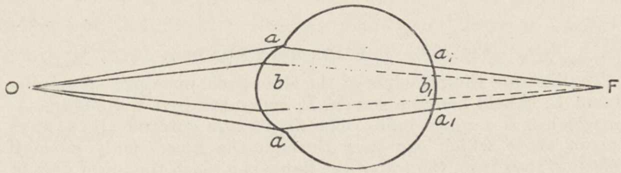


Fig. 57.—The Effect of the Size of the Pupil.

When the object O is looked at, the image is formed at F. At the level of the retina diffusion circles are formed. When the pupillary width is aa, the size of the circles of diffusion are a_1a_1; when the pupil contracts to b, the size of the circles of diffusion diminish to b_1.

refractive error might be. The principle is the same as in the pin-hole camera (Fig. 58). This is taken advantage of in a clinical test (p. 255), wherein a *stenopaeic opening* (στένος, little; ὀπή, an opening) is put before the eye and the improvement of vision is noted. For this reason, also, a hypermetrope prefers to read in brilliant illumination, so that the pupil is contracted down to a minimal size, and a myope gets into the habit of looking at objects through the half-closed lids, gaining thereby the advantages of a stenopaeic slit.

Such a procedure, however, carries with it disadvantages, for when the pupil contracts the amount of light entering the eye is correspondingly reduced and vision is rendered

Digitized by Illinois College of Optometry Library

more indistinct; at the theoretical point where it becomes infinitely small and all errors are eliminated, one ray only would enter. There are thus two opposing tendencies, each making for visual efficiency up to a certain point, and the

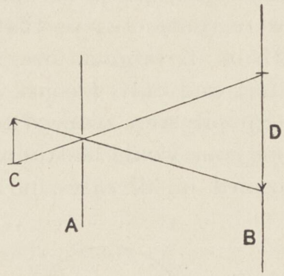


FIG. 58.—THE PIN-HOLE CAMERA.

To illustrate the principle of the stenopaeic opening. A candle-flame, C, is held before a screen, B, separated by a diaphragm, A, in which is a minute hole. The diaphragm cuts off all the rays except those which can pass through the hole. Only a small pencil of rays from the top of the flame can reach the lower part of the screen, and so on throughout its extent. A clear image, D, is therefore formed.

best results are obtained by taking a mean of both. The compromise which gives the best results varies with the illumination; where the illumination is high so as to produce a bright image, a small aperture can be used, but where the illumination is poor, better results are obtained with a greater dilatation. Under average conditions the best pupillary diameter is about 2 mm.

Digitized by Illinois College of Optometry Library

CHAPTER V

ANOMALIES OF REFRACTION

1. Hypermetropia

We have already defined hypermetropia as that form of refractive error in which parallel rays of light are brought to a focus some distance behind the sentient layer of the retina when the eye is at rest ; the image formed here is therefore made up of circles of diffusion of considerable size, and is consequently blurred.

The possibility of such a condition was first suggested by a mathematician, Kästner (1755), and about a century later (1858) was put upon a sound clinical basis by Donders, the ophthalmologist of Utrecht. He suggested the term *hypermetropia* (ὑπὲρ, in excess ; μέτρον, measure ; ὤψ, the eye). In the following year Helmholtz, writing on the subject, used the word *hyperopia ;* etymologically the word is not so good as that introduced by Donders, and it is unfortunate that it is so frequently used. Helmholtz in his later writings discarded it in favour of the original "hypermetropia."

Ætiology.—In the vast majority of cases hypermetropia is *axial,* that is, it is due to a shortening of the antero-posterior axis of the eye. This is by far the commonest of all refractive errors, and indeed forms a stage in normal development. At birth practically all eyes are hypermetropic to the extent of 2·5 to 3·0 dioptres, and as the growth of the body proceeds, the antero-posterior axis lengthens until, when adolescence is passed, the eye should theoretically be emmetropic. As a matter of fact, it is found that in over 50 per cent. of the population emmetropia is not reached, and some degree of hypermetropia persists ; on the other hand, the mark may be overshot, and the eye may become myopic

Digitized by Illinois College of Optometry Library

Emmetropia should therefore be regarded as a stage in the development in the normal eye, and hypermetropia, while it is physiological in children, represents an imperfectly developed eye when it persists into adult life. Most primitive peoples, and many of the lower animals, are hypermetropic ; carnivora, for example, are constantly so.

As a rule, the degree of shortening is not great and rarely exceeds 2 mm. Each millimetre of shortening represents approximately 3 dioptres of refractive change, and thus a hypermetropia of over 6 dioptres is uncommon. Higher degrees, however, occur, cases up to 24 dioptres without any other pathological anomaly having been recorded ; and, of course, in pathological aberrations of development such as microphthalmus, even this may be exceeded.

Shortening of the antero-posterior axis may also occur *pathologically*. An orbital tumour or inflammatory mass may indent the posterior pole of the eye and flatten it, or an intra-ocular neoplasm or deposition of exudate may displace the retina forwards at the macular region ; œdema at the optic nerve head acts in the same manner, or a more pronounced condition may be caused by a detached retina which may be displaced almost to touch the posterior surface of the lens. These, of course, form pathological instances wherein the refractive error occupies the background of the clinical picture. The main interest of its presence, indeed, is that its measurement forms a means of estimating the amount of pathological displacement, for example, in the swelling of a papillœdema ; for here again a refractive difference of 3 dioptres represents approximately an alteration in depth at the back of the eye of 1 mm.

In comparison with the aberration of the growth of the eye, which we have seen to be the most frequent cause of hypermetropia, the other ætiological factors are relatively unimportant. *Curvature hypermetropia* occurs when the curvature of any of the refracting surfaces is unduly small. The cornea is the usual site of the anomaly, and it may be

Digitized by Illinois College of Optometry Library

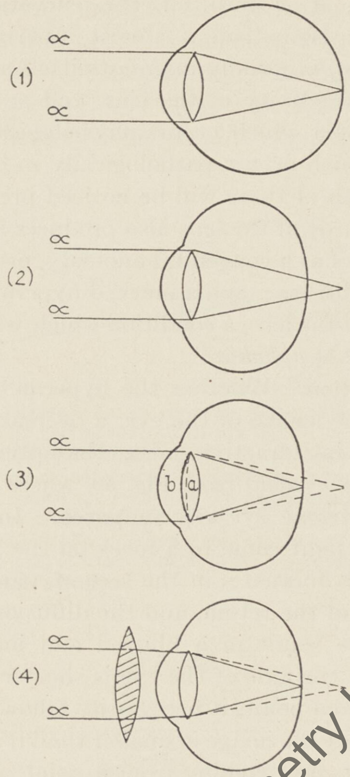


Fig. 59.—Hypermetropia.

(1) An emmetropic eye: parallel rays of light come to a focus upon the retina.
(2) A hypermetropic eye: parallel rays of light come to a focus behind the retina.
(3) A hypermetropic eye: parallel rays of light are brought to a focus upon the retina by increasing the refractivity by accommodation. The normal lens, *a*, becomes more convex, *b*.
(4) A hypermetropic eye: parallel rays of light are brought to a focus upon the retina by increasing the refractivity by a convex spectacle lens.

flattened congenitally (*cornea plana*), or as the result of trauma or disease. An increase of 1 mm. in its radius of curvature produces a hypermetropia of 6 dioptres. In these

Digitized by Illinois College of Optometry Library

cases, however, it is rare for the curvature to remain spherical, and astigmatism is almost invariably produced. *Index hypermetropia* usually manifests itself as a decrease in the effective refractivity of the lens, and is responsible for the hypermetropia which occurs physiologically in old age, and for that which occurs pathologically in diabetics under treatment. Both of these will be noticed presently. A dislocation backwards of the lens also produces hypermetropia, whether it occurs as a congenital anomaly, or as the result of traumatism or disease ; and a marked hypermetropia results in the absence of the lens, a condition which will be dealt with under the name of *aphakia*.

Optical Condition.—Whether the hypermetropia is due to a decrease in the length of the eye, a decrease of curvature, or to a change in refractive index, the optical effect is the same. It will be evident from Fig. 59, where an emmetropic and a hypermetropic eye are compared. In the first case parallel rays of light come to a focus on the retina, where a distinct image is formed ; in the second, parallel rays come to a focus behind the retina, and the diffusion circles which are formed here result in a blurred and indistinct image. Moreover, since the axis of the eye is shorter and the retina is nearer the nodal point, it necessarily follows, as is obvious from Fig. 60, that the image is smaller than it actually should be. Conversely, rays coming from a point on the retina of the emmetropic eye will emerge as parallel, while in the hypermetropic eye they will be divergent. In the first case they will meet at infinity, in the second they will only meet "beyond infinity," that is, as will be seen in Fig. 61, behind the eye. It follows that with the emmetropic eye objects theoretically at infinity, or in practice at a distance of over 6 metres, are seen distinctly when the eye is at rest, while in hypermetropia the formation of a clear image of any kind is impossible unless the converging power of the optical system is increased. This may be done in two ways—by the eye itself, or by artificial means. The curvature of the

Digitized by Illinois College of Optometry Library

crystalline lens, and therefore its converging power, may be increased in the effort of accommodation (Fig. 59 (3)). Alternatively, a convex lens may be placed in front of the eye in the form of spectacles (Fig. 59 (4)). In this case the strength of the lens required to bring parallel rays of light to a focus

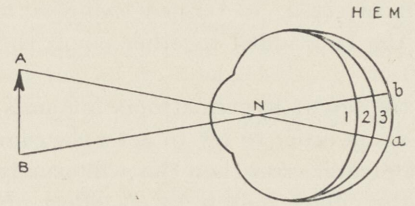


Fig. 60.—The Relative Sizes of the Image in Hypermetropia, Emmetropia and Myopia.

AB is the object and N is the nodal point of the eye. The image *ab* is obtained by drawing straight lines from A and B through N to the retina. Since the retina in the hypermetropic eye (H) is nearer to N, and in the myopic eye (M) is further away than in the emmetropic eye (E), it follows that the image of the first (1) is smaller and that of the second (3) is larger than the image in the emmetropic eye (2).

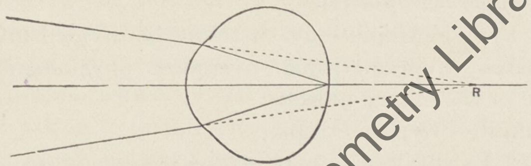


Fig. 61.—The Emergent Rays in Hypermetropia.

Rays coming from a point on the retina are divergent, and appear to come from a point (R) behind the eye.

upon the retina is a measure of the amount of hypermetropia which is present.

The Accommodation in Hypermetropia.—It has been noted that the contraction of the ciliary muscle in the act of accommodation increases the refractive power of the lens so that it can correct a certain amount of hypermetropia. Normally there is an appreciable amount corrected by the

Digitized by Illinois College of Optometry Library

contraction involved in the physiological tone of this muscle, and consequently the full degree of hypermetropia is revealed only when this muscle is paralysed by the use of a drug such as atropine. The moiety which is thus normally corrected is called *latent hypermetropia* (*Hl*). In contradistinction, the remaining portion which in normal circumstances is uncorrected, is termed *manifest hypermetropia* (*Hm*); and the two added together equal the *total hypermetropia* (*Ht*).

As a rule the latent hypermetropia amounts only to one dioptre, and so, in order to try to get a clear image, an individual with a greater error than this will usually supplement the tone of the ciliary muscle by an effort of contraction. He may correct part of his error in this way, or he may be able to correct the entire error and thus be able to see distinctly. In either case the amount corrected is spoken of as *facultative hypermetropia* (*Hf*). If the error is large, and by no effort of accommodation can he see objects clearly, the amount of hypermetropia still remaining uncorrected, and which cannot be overcome by accommodation, is called *absolute hypermetropia* (*Ha*).

Total hypermetropia may therefore be divided into:

(1) Latent hypermetropia, overcome physiologically by the tone of the ciliary muscle;

(2) Manifest hypermetropia,

(*a*) Facultative hypermetropia, overcome by an effort of accommodation;

(*b*) Absolute hypermetropia, which cannot be overcome by accommodation.

The relationship between these may probably be best understood from the method employed to determine them clinically. Let us suppose a hypermetrope cannot see a distant object clearly. We then place convex lenses of gradually increasing strength in front of his eyes until he can just see clearly; at this moment the glass and his accommodation are both acting so that with the combination of them both a distinct image is seen. The amount of hypermetropia corrected by the glass, that is, the amount

Digitized by Illinois College of Optometry Library

which his efforts of accommodation cannot correct, is the absolute hypermetropia ; and it is measured by the weakest convex lens with which maximum visual acuity can be obtained.

We now add stronger glasses until we reach the strongest with which clear vision is still maintained. During this process we have been substituting the converging power of the effort of his accommodation by the glasses and measuring the amount of hypermetropia he can correct in this way by his own efforts. This is the facultative hypermetropia ; and it is determined by the difference between the strongest and the weakest convex glass with which maximum visual acuity is obtained. The limit we have reached, that is, the strongest glass, is the measure of the manifest hypermetropia. We now instill atropine, and after a suitable interval, when the ciliary muscle has been paralysed and its tone thus abolished, we again find the strongest glass with which maximum visual acuity can be obtained. This is the total hypermetropia ; it will be found to be a little more than before by an amount which represents the latent hypermetropia.

It thus appears that a high hypermetrope, or a low hypermetrope with no accommodative power, can see nothing at all distinctly, but if the accommodation is active and the error low and within his facultative limits, he can see clearly. To a certain extent this may be an advantage, and the variability of focusing of which he is capable has been aptly compared to the position of an observer looking down a microscope with his finger on the fine adjustment. On the other hand, the constant accommodative effort which is made automatically in the instinctive attempt to obtain distinct vision frequently leads to fatigue and distress, to a disorientation between accommodation and convergence, and to other troubles which we will consider later.

The Normal Age Variation.—We have seen that in the normal individual at birth 2 to 3 dioptres of hypermetropia are present, which gradually diminishes as growth proceeds, until after puberty the refraction tends to become emmetropic. Thus Tenner found in an examination of 4,800 school children in New York, that 91 per cent. at the age of five, and only 48 per cent. at the age of sixteen, were hypermetropic. After the period of growth has passed the refraction tends to remain stationary, until in old age a further

Digitized by Illinois College of Optometry Library

tendency to hypermetropia is evident. This is due to two causes both associated with the lens. In the first place, the outer cortical layers of the lens, which are laid down in adult life, have a smaller curvature than the inner ones, a circumstance which decreases the converging power of this tissue. A more important influence is the change which comes over the refractivity of the different layers. In youth the index of refraction of the cortex is considerably less than that of the nucleus, and this inequality, resulting in the formation of the combination of a central lens surrounded by two converging menisci (see Fig. 43), increases the refracting power of the whole. In old age the index of the cortex increases, so that the lens becomes more homogeneous; acting thus as a single lens, it has less converging power than it had before, and the eye becomes hypermetropic. Thus an eye which was emmetropic at thirty years of age will show 0·25 dioptre of hypermetropia at fifty-five, an addition of 0·75 dioptre may be evident at sixty, of 1 dioptre at seventy, and at eighty years this may increase to about 2·5 dioptres. Hypermetropia of this origin is frequently designated *acquired hypermetropia*. It is to be noted that if the nucleus also increases in optical density, the original relative difference will remain, an effect which is seen to a marked degree in the excessive nuclear sclerosis which sometimes occurs in early cataract when the opposite change of myopia is frequently produced.

This increase of hypermetropia with age is real; an *apparent increase* due to the progressive failure of accommodation also occurs with advancing years. As the tone of the ciliary muscle decreases, some of the latent hypermetropia becomes manifest; and as the range of accommodation gets smaller and the possibility of correction less, more of the facultative hypermetropia becomes absolute. In early life, unless the error is unusually large, the accommodative power can correct it all, and none of the hypermetropia is absolute; after sixty-five practically all of it becomes absolute, and therefore apparent.

Clinical Pathology.—The hypermetropic eye is typically

Digitized by Illinois College of Optometry Library

small and undeveloped not only in its antero-posterior diameter, but also in all directions. The cornea is small, and since the lens varies little in shape, this structure is relatively large, thus making the anterior chamber shallow. The eye is therefore of the type which is predisposed to glaucoma, a point which should be remembered in the administration of drugs which dilate the pupil. Its smallness is usually easily recognised, and if it is rotated strongly inwards and the lids drawn outwards, the marked curve in the equatorial region forms a striking contrast to the long curve of the myopic eye. The ciliary muscle may be hypertrophied from over-use, but there are no established abnormalities in the retina choroid, or optic nerve. In the extreme degrees of the condition developmental aberrations, such as colobomata, microphthalmus, etc., are present.

It is to be remembered that although an eye is small it may be symmetrical, in which case it will not be hypermetropic ; thus the eye of both an elephant and a mouse may well be emmetropic.

Ophthalmoscopically the fundus may have a characteristic appearance, which although by no means confined to the hypermetropic eye, occurs much more commonly in this refractive condition than in any other. The retina appears to have a peculiar sheen—a reflex effect—which in its most marked degrees resembles watered silk—the so-called *shot-silk retina.* The disc frequently has a characteristic appearance which may resemble an optic neuritis (*pseudo-papillitis*). It assumes a dark greyish red colour with indistinct, and sometimes irregular, margins, whose haziness is accentuated by a grey areola around it, or by grey radial striations emanating from it, while an inferior crescent is frequently present. The condition is congenital, and its appearance is largely accentuated by reflex disturbances ; it is not altered in any way by the wearing of correcting glasses, and involves no appreciable diminution of vision ; but the resemblance to a true neuritis is often further increased by some degree of

Digitized by Illinois College of Optometry Library

swelling (always of small amount), and an engorgement of the retinal vessels. These appearances also are associated with accentuated reflexes on the vessels, which appear to alter with movements of the ophthalmoscopic mirror, and may in some cases suggest changes resembling arteriosclerosis. The vessels themselves may show congenital aberrations, for undue tortuosity and abnormal branchings are common.

The face may share with the eye in the lack of development. The orbits are typically shallow, the nose is depressed, the

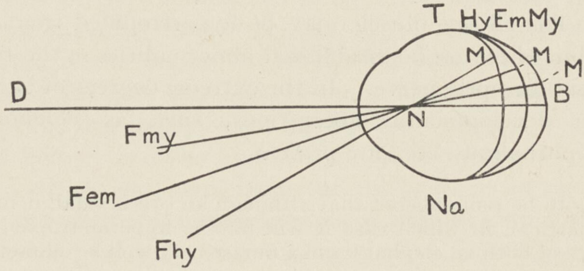


Fig. 62.—The Size of the Angle Alpha.

T, temporal side ; Na, nasal side ; DB, the optical axis ; FM, the visual axis, cutting at the nodal point, N. The varying positions of the macula in hypermetropia (Hy), emmetropia (Em) and myopia (My) determine the fact that the angle α in the hypermetropic eye (DNFhy) is greater than that in the emmetropic eye (DNFem), while in the myopic eye it is smaller (DNFmy).

face flat-looking, and the eyes placed far apart. It frequently happens that the face is asymmetrical, in which case the most markedly hypermetropic eye is usually found on the side which shows the least perfect development. This asymmetry is often seen in the eye itself, for the condition of hypermetropia is more often than not associated with astigmatism.

The macula is generally situated further from the disc than is usual in the emmetropic eye, and the cornea is more decidedly decentred ; the visual axis consequently cuts the cornea considerably to the inside of the optic axis, thus making a large positive angle alpha (Fig. 62). This in its most marked degrees frequently gives rise to an apparent divergent

Digitized by Illinois College of Optometry Library

squint, a condition the opposite of that found in myopia. On the other hand, the excessive accommodation which may be called into play excites an unusual degree of the associated function of convergence, which, as will be seen later, may result in the establishment of a true convergent squint. Frequently, especially in debilitated children, the continued muscular strain induces a state of chronic engorgement of the whole eye and the surrounding structures, which persistently look suffused and bleary, and may frequently fall a prey to low-grade infections, such as chronic conjunctivitis, blepharitis, and recurrent styes.

Clinical Symptoms.—The *visual symptoms* in the higher degrees of the error are marked, for nothing is seen clearly ; but in the lower degrees, when the accommodation is active and is able to overcome the defect, they may be entirely absent. This usually occurs in youth, when, as we have seen, a condition of mild hypermetropia is physiological. The greatest difficulty occurs in looking at near objects, for here an additional amount of accommodation is required, and starting with a certain amount of deficit, the hypermetrope is put in a disadvantageous position. Thus an emmetrope requires 3 dioptres of accommodation in order to read at 33 cm., but a hypermetrope of 2 dioptres will have to exercise 5 dioptres to get the same optical effect. When the error is large the accommodative power may be insufficient to attain clear vision, and then the tendency develops to make up for the indistinctness by an enlargement of the object ; this may be attained by holding the book very close to the eyes, an attitude which may suggest myopia. When the error is small, and accommodation is relied upon to a large extent, there may come a time when it finds itself unequal to its task. The failure may be either physiological with advancing age, or may come on in states of physical or nervous debility, and here visual acuity correspondingly suffers. Again, the trouble usually occurs on long-continued application to close work, for example, after reading for some time the vision

Digitized by Illinois College of Optometry Library

becomes blurred and indistinct, and only recovers when the patient ceases temporarily and rests his ciliary muscle.

Symptoms of eye-strain are frequent under these conditions. The headaches, the general physical disturbances and mental unhappiness to which this may give rise have been already described, and it has been explained that the syndrome is due to the excessive accommodation and to the forced dissociation between it and convergence. The condition is one of *accommodative asthenopia.* In the case of a seamstress or a compositor who works over a long day, or a student who reads closely for many hours on end, the strain thrown on the ciliary muscle is comparable to that imposed upon the leg muscles in a correspondingly long and forced march ; and it is not surprising in those whose physical or nervous condition is not of the best, or whose surroundings, from bad ventilation or other causes, are not conducive to rapid recovery from muscular fatigue, that the symptoms of distress produced in this way are a frequent cause of real suffering.

If this state of affairs persists, more definite results may ensue. Temporary *failure of the ciliary muscle* may result in obscurations of vision, or the opposite condition of *excessive accommodation*, or even *spasm of the ciliary muscle* may produce a condition of artificial myopia. The desire for accommodation in excess of convergence leads to a dissociation of muscle balance, and the struggle to maintain binocular vision in these circumstances leads to further strain. Frequently, if the fusion faculty is defective or ill-developed, the advantages of binocular vision are abandoned in favour of the more obvious advantages of clear vision, one eye only —usually the better eye—is used to the neglect of the other, and a *convergent squint* is produced. If this occurs early in life, the cerebral mechanism subserving the eye which is not used, and whose images are continually suppressed, may to a large extent lose its functional ability to interpret images, in which case the eye loses its efficiency, and

Digitized by Illinois College of Optometry Library

is termed *amblyopic*. Such a sequence usually occurs in young children who are weak or ill-nourished, or who are recovering from a debilitating illness, as measles, when they are at the stage when they first begin to fix their attention upon objects shown to them or to be interested in them. These matters will be dealt with more extensively when we are considering the anomalies of accommodation and muscular balance.

Treatment.—It may be taken as a general rule that if the error is small, the visual acuity is normal, and the patient is in good health and complaining of no symptoms of accommodative asthenopia and showing no anomalies of muscle balance, treatment of hypermetropia is unnecessary ; but if any of these conditions are violated, glasses should be prescribed.

There arises first the question of the administration of cycloplegics. About this there is considerable difference of opinion, and a greater difference between practice and precept. The subject will be dealt with in detail in a later chapter, and is only incidentally referred to here. It may be argued that theoretically, all persons in whom the accommodation is still active should be refracted with the ciliary muscle paralysed ; practically, while its marked influence makes it necessary that its action be abolished completely in all young people below the age of fifteen or sixteen by the use of atropine, such a course is unnecessary in adults who complain of visual symptoms alone. On the other hand, it is probably necessary, and certainly frequently advisable, to use a cycloplegic of less prolonged activity, such as homatropine and cocaine, in those under twenty or twenty-five, and in those above that age whose symptoms seem out of proportion to the error found, or who are suspected of an accommodative spasm, or anomalies of convergence, or in whom the objective findings obtained on examination do not agree with the subjective visual tests. It is also advisable when the best circumstances and materials are not available for conducting

Digitized by Illinois College of Optometry Library

the examination, or when the refractionist is a beginner and not an expert.

In young children below the age of six or seven, some degree of hypermetropia is physiological, and a correction need be given only if the error is high or if strabismus is present. In those between six and sixteen, especially when they are working strenuously at school, lesser errors require correction. If a squint is present, or definite symptoms of subnormal visual acuity or ocular fatigue are complained of, any error should receive attention. If a suspicion of strain is suggested by more indefinite signs—a chronic blepharitis or conjunctivitis, or an irritable or weak appearance of the eyes, a complaint of headache or unaccountable lassitude, a dislike of work and an early tiring after it is begun, rubbing the eyes and complaints of their itching, twitching of the lids, or a combination of these—an examination should be made. If the error is greater than 3 dioptres, it is probably wise to advise that correcting glasses be worn constantly; if below, it may suffice that they be used for near work alone. In the case of those who are playing boisterous games, it is well to accustom them from the start to play without their glasses to avoid the danger of their being broken, provided that their vision is adequate to allow them to play efficiently; if it is not, special protective glasses (such as triplex or rowlite) should be used on these occasions.

In all these cases the examination should be conducted under atropine. As a general rule, in ordering the glasses, 1 dioptre is deducted from the objective findings to allow for the tone of the ciliary muscle. This rule may not always be adhered to in cases of strabismus, when slightly less may be deducted—a subject which will be treated later; but in younger children below the age of six, especially if the error is high, more should be deducted. At this age subjective tests are not available or are of little value, and 1·5 or 2 dioptres can well be deducted. In older children, as close an approximation to this generalisation as possible should be

Digitized by Illinois College of Optometry Library

attempted, always remembering that if glasses make a child's vision worse, it is a very difficult thing to make him wear them conscientiously. It is usually safest to prescribe the fullest correction consistent with good vision which he will accept, and it is usually found that a child will tolerate his normal correction with ease; but in the other alternative, if the symptoms indicate that a determined attempt should be made to reduce his refraction as nearly as possible to emmetropia, as, for example, in cases of squint, weak atropine may be given every second day for a week or two until the ciliary muscle becomes accustomed to its new conditions of work.

It is important to remember in all these children that hypermetropia tends normally to diminish with growth, and consequently the refraction usually approaches emmetropia gradually until adolescence is passed. Children should thus be examined once a year, and their glasses changed if necessary, lest a glass which is over-correcting their error may induce an artificial myopia. For this reason it is the rule that glasses of progressively diminishing strength are required, until finally, in some cases, they may safely be discarded altogether.

In older people the advisability of wearing glasses depends upon the degree of vision and on the symptoms complained of: one person with 1 dioptre of hypermetropia will complain bitterly, while another with 3 dioptres will be quite comfortable. Young adults with an error of 3 dioptres who have normal vision and are without symptoms should rarely be corrected, for glasses of any kind carry with them physical and optical disadvantages which make their unnecessary use inadvisable. Inversely as is the case with children, the decline of accommodative power in middle and later life makes lenses of gradually increasing strength necessary. An adult with 3 dioptres of hypermetropia may be comfortable at twenty-five, but at thirty-five the additional accommodation required for near work will begin to tax his declining

Digitized by Illinois College of Optometry Library

power, and he may require a correcting glass for reading; in such a case, if the glasses do not improve the distance vision and there are no symptoms of asthenopia, they need not be worn constantly, but only for close work. But in later life, when his accommodation has gone and all the hypermetropia has become absolute, distance glasses also will be necessary.

If visual symptoms alone are complained of and the refraction is not done under a cycloplegic, it is usually sufficient, after refraction, to order the strongest glasses with which maximal visual acuity can be obtained with both eyes: this will be found to be slightly higher (about 0·25 D) than the correction which each eye will tolerate separately. If circumstances indicate that a cycloplegic should be used, there is some difference of opinion as to the amount of the total hypermetropia which should be corrected. It might be thought that it would be advisable to correct the whole of the hypermetropia and thus place the patient in the position of an emmetrope; but it must be remembered that in these subjects the ciliary muscle has been accustomed to exercise an abnormal amount of accommodation, and the excess of activity usually results in its permanent hypertrophy. Consequently, with the latent accommodation which they naturally use, and which they can only renounce with difficulty, a full correction would render them myopic, distant vision would become indistinct, and the glasses, giving rise to a fresh crop of troubles, would not be tolerated. Moreover, such a course, if persisted in until the accommodation has got tuned down to the requirements of emmetropia, would carry with it the inconvenience that such a patient would be unable to see at all efficiently whenever he removed or was deprived of his spectacles. It would seem advisable, therefore, to under-correct the total hypermetropia. On the other hand, it frequently happens that the headaches, the asthenopia, and the referred symptoms return if a part of the hypermetropia remains uncorrected; we are thus faced with a dilemma whose solution frequently calls for no little judgment.

Digitized by Illinois College of Optometry Library

In such cases it is quite inadequate to be guided by hard and fast rules, such, for example, as the well-known one to deduct from the total hypermetropia 1 dioptre if it be estimated under atropine, or 0·75 if homatropine be employed. It is generally best to determine the manifest hypermetropia and base the strength of the glasses upon this.

We have seen that the manifest hypermetropia is measured by the strongest convex lens with which distant objects can be seen clearly ; since a distance of 6 metres is used in practice instead of the theoretical infinity, inasmuch as the rays from such an object are not parallel, but slightly divergent, an amount between one-quarter to one-sixth of a dioptre should be deducted from the clinical findings in estimating this. It will be remembered, incidentally, that the latent hypermetropia is the difference between the total and the manifest. Donders advised that the glass ordered should correspond with the manifest hypermetropia plus one-quarter of the latent, a suggestion which has received very general acceptance. This, however, although a good working rule, will be frequently found inadequate. The most practical method appears to be to consider each case on its own merits individually, to determine the manifest hypermetropia and order glasses on this basis, correcting the patient as nearly to his total hypermetropia as possible, while remaining within the limits consistent with comfort and good vision, at the same time paying regard to his age, to the state of his accommodation, his symptoms, his muscle balance, his general physical and nervous state, and his vocation.

The younger a patient is, the more active is his accommodation, and the more we may under-correct. The greater the latent hypermetropia, that is, the greater the residual accommodation, the more we under-correct. On the other hand, if his symptoms of eye-strain are marked, especially in the presence of neurasthenia and muscular weakness, we correct as much of the total hypermetropia as possible, trying as far as we can to relieve the accommodation, especially in

Digitized by Illinois College of Optometry Library

cases of nervous debility and in those recovering from illness. Where there is spasm of the accommodation we correct the whole of the error, as also where there is a tendency to latent convergent squint, with a view in the first case to force rest upon the ciliary muscle, and in the second, to relieve convergence indirectly by relieving accommodation. In both cases we insist that the spectacles be worn constantly. Conversely, if there be latent divergent squint, we under-correct in the hope that, by stimulating accommodation, we may stimulate convergence. On the whole, if the patient leads a sedentary and studious life, we tend to correct more of the hypermetropia than we would if he had little to do with the study or the desk and lived mainly out-of-doors.

Generally, the more fully corrected the error is, the better the result, always provided that the glasses are compatible with good vision; but if the amount which we would like to give is refused on this account, it is usually well to temporise. Children usually accept a reasonably full correction with ease; but to many adults it brings genuine distress, in some cases inducing symptoms of eye-strain for the first time, in others making their previous discomfort worse. It is often remarkable how great a difference a diminution of strength of even 0·25 D may make to their comfort on occasion, and the frequent omission to deduct the amount of excess due to the estimation of the manifest hypermetropia at 6 metres instead of infinity, accounts for much unpleasantness. Small errors in the adjustment of the spectacles, their distance from the eye, and other points, are also of considerable importance; these will be dealt with subsequently. As a compromise in a difficult case, it may be well to under-correct considerably at first, and to strengthen the lenses at intervals of about six months until the full correction is comfortably borne; or it may help to advise a weaker glass than is correct for distance and the full correction for close work. But in those cases where adequate correction is necessary, as in spasm of accommodation, and in excessive convergence, every

Digitized by Illinois College of Optometry Library

endeavour should be made to induce the patient to wear the glasses even at the cost of some discomfort ; sometimes, where it is not contra-indicated, and economic conditions do not preclude it, the instillation of weak solutions of atropine may help very considerably in tiding over the difficult initial period.

Finally, it is to be remembered that the symptoms of accommodative asthenopia frequently have a significance deeper than their superficial consideration would indicate. The delicate adjustment of the eye serves as an index of the general constitutional state, and the onset of fatigue here should suggest its imminence elsewhere : the eye-strain is a symptom of general strain. Treatment, if it is to be adequate, should not be confined to the correction of the optical apparatus alone, but should include an inquiry into the general physical and nervous state, and, if necessary, should involve a re-organisation of the habits and activities of the individual, so that he lives within the limits of his capabilities. Thus typical symptoms come on in the child starting school, in the youth studying for an examination, in the girl leaving the comparative ease of home life and setting out in business, in the adult in periods of over-work and anxiety, and in them all in states of physical debility and mental depression. Interpreted in this light, the development of failure to compensate for hypermetropia may be the means of calling attention to the existence of a more deeply-seated trouble before it would have otherwise enforced recognition—it is an "early symptom" ; and if its true significance is neglected and treatment is confined to the ocular condition alone, sufficient relief and encouragement may be given to the patient to make it possible for him to carry on until a breakdown of a more serious nature may be unavoidable (see p. 19).

Digitized by Illinois College of Optometry Library

CHAPTER VI

ANOMALIES OF REFRACTION

2. Myopia

Myopia (μύω, I close; ὤψ, the eye), or short sight, is that form of refractive error wherein parallel rays of light come to a focus in front of the sentient layer of the retina when the eye is at rest; the eye is thus relatively too large, and the condition is the opposite to that of hypermetropia.

The term myopia was introduced from the habit which short-sighted people frequently have of half-closing the lids when looking at distant objects so that they may gain the advantages of a stenopaeic opening (see p. 77). Of late years a term in conformity with other refractive designations—*hypometropia*—has appeared in American writings.

The first satisfactory definition of the condition was stated by Kepler in 1611, and Plempius (1632) first examined the myopic eye anatomically and attributed the condition to a lengthening of its posterior part. Donders (1866) established its pathological cause, and put its clinical manifestations upon a sound basis.

Ætiology.—In the very great majority of cases myopia is *axial*, that is, it is due to an increase in the antero-posterior diameter of the eye. Compared with this, the other causes are unimportant.

Curvature myopia may be associated with an increase in the curvature of the cornea or one or both surfaces of the lens. An increased curvature of the cornea not infrequently occurs, but it is usually evident as an astigmatic rather than a spherical error. Small deviations from the normal are common, since the radius of the cornea varies within the normal limits of 7 to 8·5 mm., a variation which involves a refractive difference of two-thirds of a dioptre. This factor has no influence on the occurrence of the usual axial type of

Digitized by Illinois College of Optometry Library

myopia, for in this condition the cornea is usually flatter than normal. Pronounced cases of a true increase of corneal curvature only occur in diseased conditions, as ectasias or conical cornea.

Increase of lenticular curvature is also rare; in fact, corresponding to the state of the cornea, the lens is usually flat in typical axial myopia, tending, as it were, to correct the error. Conditions of anterior and posterior lenticonus occur, which may involve a marked degree of myopia. The curvature of the surfaces is also increased whenever the suspensory ligament is relaxed. This occurs in the most extreme degrees when the ligament is ruptured and the lens dislocated, for in this state the elasticity of the capsule makes the lens assume an almost spherical shape. Thus in a case of ectopia lentis, Hess found a refraction of + 10 D in the aphakic part of the pupil and — 15 D in the phakic part. A similar relaxation also occurs in spasm of the accommodation, which thus induces an artificial myopia; and a transient myopia of the same type has been noted in cases of irido-cyclitis, due presumably to an irritative contraction of the ciliary muscle as the result of inflammation. In advanced diabetes, when the sugar content of the blood is high, the osmotic attraction of fluid into the lens may also deform it; and the sudden onset of myopia in an adult should always suggest the possibility of this condition (see p. 153).

Index myopia is also relatively unimportant. A change of refractive index of the aqueous or vitreous can never be so great as to exercise any appreciable effect in conditions compatible with life. A decrease in the index of the cortex of the lens, or an increase in that of the nucleus, will have a greater effect: the first of these probably exerts an influence in the production of diabetic myopia when the periphery of the lens draws in fluid; while the second, when the nucleus becomes disproportionately sclerosed, accounts for the myopia met with in cases of incipient cataract.

Digitized by Illinois College of Optometry Library

Typical myopia, as we have noted, is *axial;* and this is a common condition affecting 20 per cent. of the population. In contradistinction to hypermetropia, which is congenital, myopia is acquired, and should be looked upon rather in the light of a disease: this certainly applies to its more advanced states. It is found at birth very rarely indeed: cases of buphthalmus, which may simulate it, have quite a different pathology.

In *buphthalmus*, a condition of congenital or infantile glaucoma due to defective development or early inflammation, the whole eye is enlarged, and the antero-posterior diameter greatly increased. As Parsons pointed out, however, the axial myopia which is produced in this way is much less than might be expected, for it is counteracted to a large extent by the flatness of the cornea and lens and the displacement backwards of the latter.

We have seen that in the new-born the normal eye is hypermetropic, and that as age progresses and growth proceeds, this tends to diminish. In some cases the hypermetropia remains, in others emmetropia is reached and development becomes stabilised at this point, while in others the tendency progresses and a greater or less degree of myopia results. The period of growth is therefore the crucial one from the standpoint of myopia, and if the hypermetropic eye be considered an undeveloped eye, the myopic one might be considered, in a limited sense, over-developed. Since a short-sighted person can see minute objects more distinctly close at hand than an emmetrope, it has been suggested that myopia is an adaptation to the conditions of civilised life with its necessities for close work. Such a teleological explanation has little to recommend it, for the condition comes on in early life when the small relief it affords is inappreciable and purchased at a high cost, and it never develops after middle life when, with the failure of accommodation, it would be really advantageous. Myopia should be regarded not as an adaptation to civilisation, but rather as one of its penalties.

Digitized by Illinois College of Optometry Library

The ætiology of axial myopia has given rise to a very large amount of speculation and controversy, and numberless theories have been put forward at various times to explain its incidence. It appears probable, however, that its occurrence is determined by two considerations: one, an essential and predisposing cause—a weakness of the sclerotic and its consequent inability to withstand the normal intraocular pressure without giving way and stretching; the other, a varying number of incidental and determining causes without whose added influence the first would not necessarily be effective. The most important of these are near work, bad ocular hygiene, and physical debility.

The *essential cause*, weakness of the sclerotic, is primarily an aberration of development. It is seen in the fact that the condition, while rarely congenital, may come on very early in life, and is definitely hereditary, and to some extent racial. The outer coat at the posterior pole is frequently thinner than can be accounted for by mere mechanical distension, and may have a thickness of only 0·11 mm. Myopic changes, moreover, may be said to come on only during the period of active growth, for elongation of an eye which has remained of normal dimensions up to the age of twenty is rare. The eye shares with the brain the peculiarity of having a precocious growth, for at the age of four the brain is 84 per cent. of its full size, the eye 78 per cent., and the rest of the body only 21 per cent. After this both eye and brain increase in size slowly until at about twenty years the adult dimensions have been reached. One of the most rational explanations which have been advanced interprets myopia as a continuation of this precocity, and a failure of the arresting influence to act. What this influence is, is not definitely known; but, as Sir Arthur Keith pointed out, one of the controlling factors which regulate the activities of fibroblastic cells (for of such the sclerotic is composed), is the endocrine system, more especially the pituitary body. An extreme degree of the effects of a fault in this mechanism

Digitized by Illinois College of Optometry Library

throughout all the skeletal tissues is seen in such a disease as acromegaly, and minor deformities of the skull and a calcium deficiency in the blood are common in myopia.

The occurrence of myopia after the period of growth has passed is rare, and, apart from its incidence in a few cases of severe choroiditis, it has been reported, and that but seldom, mainly in conditions of goitre and obesity and in association with pituitary struma. An endocrine dyscrasia, moreover, will account for the peculiar intermittency which the progress of the disease frequently shows. The growth and development of the sclerotic is essentialy bound up with the growth and development of fibroblastic cells, and some such comparable dyscrasia in the controlling mechanism is probably the essential feature of the ætiology of myopia, although the exact nature of the defect is a problem as yet unsolved.

In the great majority of cases it appears that this alone is not sufficient to determine the onset of the condition: the influence of one or more *adjuvant factors* is required. The most important of these is without doubt near work, especially when it is enforced early in life at about the fourth year in a child whose physical condition is poor. Its deleterious effects are reinforced by too long hours of application with insufficient intervals of relaxation between them, poor illumination and faulty ventilation, the use of books poorly printed in small and closely-spaced type, and the provision of badly-adjusted desks and stools which necessitate a strained and unhygienic attitude. Statistics have conclusively shown that the proportion of myopes increases rapidly and steadily during the years of school life in a ratio greater than its mere age-incidence warrants; thus Cohn found 1·4 per cent. in the lower grades of schools, a proportion which steadily rose up to 60 per cent. in the universities. Statistics also show that myopia is unduly common in those occupations where the eyes are assiduously used for study or the close inspection of minute objects. On the other hand, in peasants and in

Digitized by Illinois College of Optometry Library

savages it is rarer. It is true that these statistics are in many ways open to question, for a myope will choose preferentially an occupation which involves close work, and a short-sighted savage will have little chance of survival. In addition, it is to be remembered that the condition does occur in the illiterate and in those who do little or no close work, while the highest degrees are as common among peasants as among the educated classes. Moreover, large numbers of those who are exposed to all these adverse conditions never develop myopia. While, therefore, near work cannot be stigmatised as the essential cause of the condition, it undoubtedly seems to have a deleterious effect upon the progress of the disease.

The manner in which it acts has been explained in several ways. The excessive convergence associated with the attempt to look at near objects involves pressure of the extrinsic muscles upon the globe which deforms the eye. Increased intra-ocular tension results from this muscular pressure, and also from vascular congestion due to the dependent position of the head and, in the initial stages of the disease, to a continued over-action of the ciliary muscle in its attempt to accommodate, a factor which is accentuated when astigmatism is present.

A very large number of further theories have been suggested. Excess of accommodation has been indicted (Erismann and others), in that it raises the intra-ocular pressure—which is untrue—or that the ciliary muscle pulls upon the choroid (Iwanoff); deficient accommodation, in that the pumping action of the ciliary muscle through the scleral spur of Thomson in the canal of Schlemm is deficient, thus raising the tension by preventing the drainage of aqueous (A. Wood). Alternatively, there is obstruction to the outflow of fluid in the lymph spaces associated with the optic nerve head (Edridge Green). Convergence has been blamed, acting either by the muscles pressing directly against the globe, or by their obstructing the outflow of the vortex veins (Ault); some regard the recti as the offending muscles (v. Graefe), others the superior oblique (Philipp, Stilling, etc.). Congestion is supposed to be conditioned by manual labour, especially when stooping, by gymnastics, etc. (Edridge Green); or, alternatively,

Digitized by Illinois College of Optometry Library

by disease, as cardio-vascular or nasal troubles (Batten). An inclusion of excess of mesoblastic vitreous material into the secondary optic vesicle is believed by some to be the cause; an excessive development of the retina by others (Vogt); a shortening of the optic nerve pulling upon the posterior pole of the eye (Hasner, Emmett, Weiss); or a posterior sclero-choroiditis softening it (v. Graefe). The shape of the orbits has been called into question, since it is said to influence the shape of the eye (Amadei, Bono), or, by increasing the inter-pupillary distance, to increase the effort necessary for convergence and thus influence the degree of muscle pressure upon the eye (Mannhardt, Adamük). The action of gravity when the head is bent is said to elongate the eye (Levinsohn). These, and many more: most of them remarkable for their ingenuity rather than their value.

The Progress of Myopia.—We have seen that myopia is rare at birth; it is usually said to commence during the third or fourth years of life, but its origin from the usual initial state of hypermetropic astigmatism properly dates almost from birth. Hypermetropia, as we have seen, is congenital and stationary; myopia, on the other hand, is a progressive disease. In most cases the myopia is of a relatively low degree, not exceeding 5 or 6 dioptres, and when the period of adolescence has passed, it tends to become arrested. Progression is usually slow and steady until puberty, which seems to exercise a restraining influence, and final stability is reached about the age of twenty-one. If, however, the error progresses rapidly in early youth, it is less likely to become stationary, and may finally amount to 20, 25, or even 30 dioptres; in these cases the period of most rapid progression is usually from fifteen to twenty years. After this the process usually tends to slow down, but in the highest degrees vision may steadily deteriorate, until about sixty blindness may ensue. In the lesser degrees, the tendency to hypermetropia owing to the changes in the lens which occur in old age, appreciably diminishes the myopia.

Clinical Types.—The usual type of myopia, the progress of which begins to diminish at puberty and which stabilises at twenty, and which is limited to an error of about 6 dioptres, is called *simple myopia.* That which steadily increases is

Digitized by Illinois College of Optometry Library

called *progressive or malignant myopia.* It is impossible, clinically or pathologically, to draw a distinct line of demarcation between the two types, and the theory of their ætiological independence has little to recommend it. In the first case the " restraining influence " acts a little late, but nevertheless efficiently ; in the second, it does not act at all.

Clinical Pathology.—The elongation of the eye which

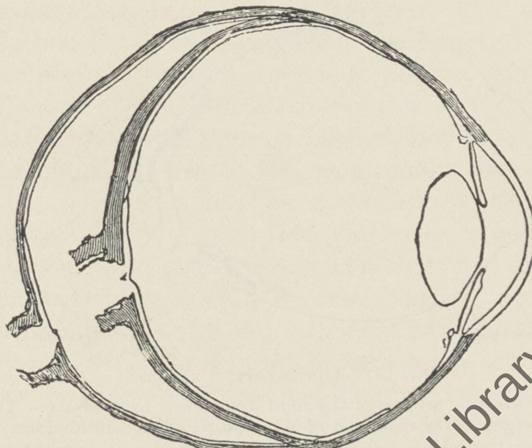


Fig. 63.—The Deformation of the Eye in Myopia.

An emmetropic and a myopic eye compared. It is seen that the deformation affects the posterior part of the globe only, while the anterior part is normal. (After Heine.)

results in myopia is almost entirely confined to the posterior pole, and the anterior half of the globe is usually normal (Fig. 63). The eye, however, is generally obviously large and prominent, and when it is turned strongly inward so that the equatorial region appears in the outer part of the palpebral fissure, the flatness of its curvature is obvious. The anterior chamber is deep, and the pupil usually dilated and somewhat sluggish. The absence of any stimulus to accommodate allows the ciliary muscle, especially its circular part, to

Digitized by Illinois College of Optometry Library

become atrophied, and the lens may become sufficiently unsupported to allow the iris to be slightly tremulous. The posterior segment of the sclerotic is thinned, and in extreme degrees may be reduced to a quarter or less of its normal thickness.

Ophthalmoscopically, the main changes observed are the generalised atrophy of the retina and choroid, the myopic crescent at the disc, the disturbances at the macula, the

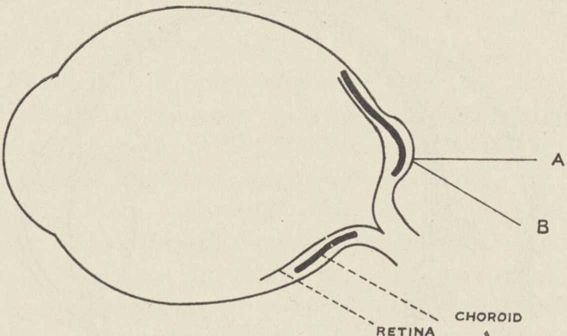


Fig. 64.—The Myopic Crescent.

A horizontal section of the right eye viewed from above. Traction occurs in the direction of A; and its effect will obviously be to drag the retina and choroid away from the disc on the temporal side, forming the myopic crescent, and to pull these structures over the disc on the nasal side, forming the supertraction crescent.

occurrence of a posterior staphyloma, and the presence of Weiss's reflex streak.

The changes in the choroid and retina are degenerative and not inflammatory. The pigment layer of the retina loses much of its pigment, so that the fundus is tigroid and the choroidal vessels are well seen. Patches of choroidal atrophy appear leaving white areas surrounded by pigmentary changes, and the stretching may produce haemorrhages and actual rents; finally an accumulation of thin large white patches associated with splotches of pigment may be scattered all over the fundus. At the macula such an atrophic patch is common,

Digitized by Illinois College of Optometry Library

and this is accompanied by the abolition of central vision. A similar disastrous result is produced by the appearance of a dark circular area in this region. This is relatively rare and may occur suddenly, when it is probably caused by an intra-choroidal haemorrhage or thrombosis; otherwise it may be due to a dense localised thickening of the retinal pigment epithelium. Small dark spots resembling haemorrhages are relatively common near the macula, but since they undergo no change for an indefinite time, they are probably bunches of dilated choroidal capillaries.

At the disc the elongation tends to produce the characteristic crescent. The bulging backwards of the posterior pole (A, Fig. 64), drags the retina and choroid from the temporal margin of the disc, leaving an atrophied part through which the sclerotic is seen as a white area (the *myopic crescent*), while on the nasal side, the retina is pulled over the edge of the disc, thus blurring its margin, and conditioning the so-called *supertraction crescent*. The myopic crescent is usually temporal, but it may extend as an annular ring all the way round the disc. In the higher degrees the whole of the posterior pole of the eye may herniate backwards as a *posterior staphyloma*. This is recognised ophthalmoscopically by the sudden kinking of the retinal vessels as they dip over its edges in the same way as they dip into a glaucomatous cup. Pathologically, such a state results in gross atrophic changes, and optically, of course, its effect is disastrous.

These changes by no means always run *pari passu* with the degree of myopia, and very high errors may exist with few gross lesions in the fundus. In all cases the condition of the choroid is one of stretching and atrophy, with little or no evidence of inflammation, while the retinal changes are degenerative, secondary to those of the choroid. Similar mechanical and degenerative changes occur in the vitreous. Detachment of the vitreous may occur at the posterior pole, and a collection of fluid in this region may give rise to the reflex streak described by Weiss; the vitreous itself

Digitized by Illinois College of Optometry Library

frequently liquefies, obvious muscæ volitantes are almost invariable and large floaters are common.

Complications usually take the form of tears and haemor-

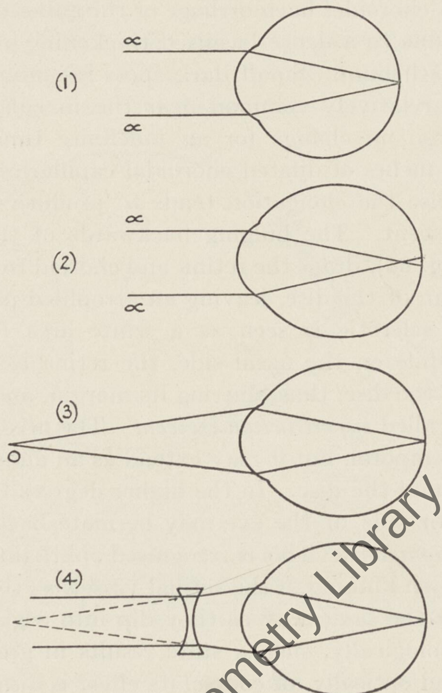


Fig. 65.—Myopia.

(1) An emmetropic eye, parallel rays being focused upon the retina.
(2) A myopic eye, parallel rays being focused in front of the retina.
(3) When looking at a near object (O), the divergent rays are focused upon the retina. O is the far point.
(4) A similar divergence may be given to parallel rays by a concave lens so that a focus is again formed upon the retina.

rhages in the retina, and its more or less extensive detachment: this may be associated with trauma, but, on the other hand, may occur spontaneously. Some loss of vision may also be determined by the degenerative changes in the

Digitized by Illinois College of Optometry Library

vitreous, while similar processes in the lens may lead to the formation of opacities, the most typical of which is a posterior cortical opacity.

Optical Condition.—In the myopic eye parallel rays of light come to a focus in front of the retina; here they cross, and the image is therefore made up of the circles of diffusion formed by the diverging beam (Fig. 65 (2)). It follows that distant objects cannot be seen clearly; only divergent rays will meet at the retina, and thus, in order to be seen clearly, an object must be brought close to the eye, so that the rays coming from it are rendered sufficiently divergent (Fig. 65 (3)). This point, the furthest at which objects can be seen distinctly, is called the *far point* (*punctum remotum*). In the

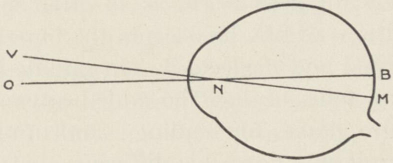


Fig. 66.—The Negative Angle Alpha in Myopia.

This does not occur invariably. Usually the angle α is posterior, but smaller than in hypermetropia; see Fig. 62. OB is the optic axis; VM, the visual axis; N, the nodal point; and angle ONV, the angle α.

emmetropic eye it is at infinity; in the myopic eye it is a finite distance away, and the higher the myopia, the shorter the distance. This distance is thus a measure of the degree of myopia: if the far point is 1 metre from the eye there is 1 dioptre of myopia, if it is 2 metres away, there is 0·5 dioptres, and so on.

If they are to be brought to a focus at all, parallel rays coming from distant objects must be rendered more divergent, and this we can do by placing a diverging lens in front of the eye (Fig. 65 (4)). If the far point is 1 metre away, a lens of the strength − 1 D will render parallel rays as divergent as if they came from this point, and therefore the weakest con-

Digitized by Illinois College of Optometry Library

cave lens with which normal distant vision is attained is a measure of the degree of myopia. To some small extent the myope compensates for his poor visual acuity, for, since the nodal point is further away from the retina, the image here, as is seen in Fig. 60, will be appreciably larger than it would be in the emmetropic eye.

There may be an apparent convergent squint due to the presence of a negative angle alpha (Fig. 66).

Clinical Symptoms.—The *visual defect* is the most prominent symptom of myopia. Curiously, in its slighter degrees it may in many cases appear to be an advantage. Accustomed to defective vision from the time when he began to look upon the world intelligently, the myope frequently fails to recognise his limitation. Especially when his close attention is required largely for near work, as so often happens under civilised conditions of life, he accepts the blurring of distant objects as normal and neglects it. In middle life, when his accommodation fails, he has the added advantage that he does not require glasses for reading; and in old age, as his contracting pupil cuts down his diffusion circles, and as the senile changes in his lens bring on a relative hypermetropia, he is in the happy position of finding his vision gradually improving. And so it happens that at eighty he is the envy of his hypermetropic contemporaries and the pride of his bespectacled presbyopic children.

Where good visual acuity at a distance is required, however, the smaller errors are incapacitating, and if the myopia is present in any marked degree the visual disability is always serious. Distant objects are seen indistinctly, and to be appreciated, everything must be brought close up to the eyes. The disability from which such a person suffers can be appreciated by an emmetrope if he holds a convex lens in front of his eyes. In the attempt to improve the distant vision the lids are screwed up to form a stenopaeic slit, while the tendency to pore over near work engenders the habit of stooping and, especially in adolescents, perpetuates the

Digitized by Illinois College of Optometry Library

deformity of rounded shoulders. Where the error is large the visual loss is correspondingly grave. The field is constricted, the more so when correcting glasses are worn, so that the whole head has to be orientated in the direction of the line of vision. Although the images are to some extent enlarged, the visual acuity, even when corrected, is frequently below the normal; this is probably partly due to the degeneration and disappearance of the retinal pigment. When atrophic patches appear, actual scotomata result, a complication which is seen in its most incapacitating form when, as so frequently happens, the macular region is affected, and central vision is lost. The degenerated and liquefied vitreous abounds in muscæ volitantes and floating opacities, and these, throwing abnormally large images upon the retina, although their actual significance is small, cause a great deal of annoyance and anxiety to the patient. Matters tend to progress slowly and relentlessly, the patient all the while never using his eyes with comfort, until finally no useful vision may remain, or until the occurrence of a sudden calamity, as a gross macular lesion or a retinal detachment, ends the matter more dramatically.

In the smaller degrees of error especially, symptoms of *eye-strain* are evident, although generally not so obviously as in the case of the hypermetrope. Pain, fatigue, an intolerance to light, and a constant irritability of the eyes associated with hyperæmia of the lids, are frequently present. The excess of convergence which the close application to work entails, disorientates the accommodation which is not required at all. The physiological impulse for the two related functions to work together may have one of two opposite results. The accommodation may attempt to equal the convergence, and ciliary spasm comes on, thus artificially increasing the amount of myopia. Alternatively and more frequently, the attempt at convergence is given up, its latent insufficiency gives rise to the troubles of muscular imbalance, until finally the advantages of binocular vision are abandoned,

Digitized by Illinois College of Optometry Library

one eye alone is relied upon, and the other deviates outwards, the usual apparent convergent strabismus giving place to a true divergent squint (see p. 236).

These troubles, it has been remarked already, reflect upon the general mental attitude of the individual. The fact that efficiency can only be easily attained at close work, tends to stimulate studious habits and a reserved disposition, which while it may serve its purpose, may not seldom result in a tendency either to shyness or self-complacency. Cut off from a full appreciation of the happenings in the world around him, and denied a realisation of their finer shades of expression, the high myope loses much of the benefits of sport and play when he is young, and only with difficulty keeps pace with his more fortunately equipped fellows in the more strenuous and more exacting pursuits of later life.

Prognosis.—The prognosis of myopia depends very largely upon the age of the patient. Any degree occurring in a child under the age of four should be regarded as a serious condition requiring treatment: unless active precautions are taken, and frequently in spite of these precautions, it is almost certain to progress, until eventually it is attended by serious changes in the fundus and grave defects of vision. Above this age, and certainly above the age of eight or ten, low degrees—up to − 6 D—may be looked upon with less alarm; care should be exercised especially between the time of puberty and twenty-one, and if this period is passed, the condition may be expected to remain stationary, and the prognosis may be taken as good. In the higher degrees the prognosis should always be guarded; it must be based on the appearance of the fundus and the acuity of the vision after correction. In all cases the possibility of a sudden haemorrhage or a retinal detachment should be borne in mind.

Prophylaxis.—Since we are ignorant of the mechanism of the essential cause of myopia, we must, in the present state of our knowledge, limit ourselves to minimising as much as

Digitized by Illinois College of Optometry Library

possible the adjuvant causes which are within our power to attack. We have seen that the evidence is indisputable that the most important accessory factors in the ætiology of the condition are excessive near work, bad ocular hygiene, and physical debility in the early years of growth ; if more attention were paid to the elimination of these, the incidence of myopia would undoubtedly fall. It is certainly the case that the *régime* of modern schools imposes far too much application to books upon young children at an age when they require all their available vitality for physical growth and development. The establishment of kindergarten schools, many of which are unscientifically run, has intensified the evil by introducing these disadvantages at an earlier age. Until the age, at least, of four, a child's attention should be taken up solely by open-air pursuits and his interests should not be chained to play-studies indoors. In the exigencies of our artificial civilisation, early application to work may be an advantage in some respects, but it is an advantage too frequently gained at a cost.

If early studies are necessary, every care should be taken that the health and general vitality be kept vigorous, and after any illness, or during any period of debility, near work should be rigidly excluded. Reading in bed or when tired should be forbidden, and the stupidity of expecting a child to do what a fully developed man in the years of his discretion usually refuses to do, should be realised—to work indoors in the evening after working indoors all day. Both at school and at home work should be undertaken only when the illumination is good and well distributed, when the books employed have heavy and large print, and when the chair and the desk allow of an easy and natural attitude and render stooping and strain impossible. Most important of all, the eyes of every child should be examined at yearly intervals as long as he is engaged upon study during the period of growth, and any refractive error corrected, and his conduct and pursuits regulated accordingly. Finally, whenever there is a

Digitized by Illinois College of Optometry Library

hereditary tendency to myopia, these precautions should be more rigidly insisted upon.

Treatment.—Once it has been established, myopia cannot be cured, but every endeavour should be made to try to arrest its progress. Fortunately, in many cases, this can be done by the provision of glasses which correct the optical error, and by paying adequate attention to the habits of the patient and the general hygiene of his surroundings.

In the *ordering of glasses* for young people atropine should always be used. In cases of *low degrees* of myopia (up to — 6 D) in young subjects, while the defect should never be over-corrected, a full correction should be ordered and advised for constant use. Opinions vary upon the advisability of this procedure ; and it will frequently be found that such a correction will not be acceptable for near work. The patient has been accustomed to read without exercising his accommodation, and as far as his near work is concerned, he may be more comfortable without glasses at all, or with a weaker lens. This he is able to do, however, only by holding his book too closely to his eyes, by straining his convergence, and by dissociating it from his accommodation. By giving him his full correction, we place him in the position of the emmetrope, and accommodation and convergence are forced to resume their natural relationships. It should be impressed upon him that, in the matter of near work, his glasses are not intended to improve his vision, but to make him read at the proper distance and bring his eyes into their normal relationships. There is an abundance of statistical evidence to show that this procedure holds out the most reasonable chance of rendering the myopia stationary, and its adoption should be insisted upon in all low grades of the condition occurring in adolescents below the age of twenty to twenty-five. In adults above that age it will frequently be found that the atrophic ciliary muscle is not equal to the unaccustomed task of accommodating efficiently, and if this be the case, a lens of slightly lower power (1·5 or 2 D) may be

Digitized by Illinois College of Optometry Library

prescribed for reading, especially if engaged in to any great extent. This course should only be adopted, however, if the full correction brings with it discomfort, and the weaker glasses should be used only when fine work is done. Above the age of forty, of course, when accommodation fails physiologically, a weaker glass for near work is essential.

In the case of *high myopes*, this counsel of perfection will be found impossible, for the full correction can rarely be tolerated. As will be explained later, strong concave glasses diminish the size of the retinal images, making them at the same time very bright and clear; and the retina of the high myope is irritable and intolerant to light, and has been accustomed to hazy diffusion circles. A compromise must therefore be adopted, and while we attempt to reduce the correction as little as is compatible with comfort for binocular vision, we prescribe the lens with which greatest visual acuity is obtained without distress. The amount which has to be deducted usually varies from 1 to 3 D, but in the highest grades, glasses even weaker than these will be found necessary; the patient should be allowed to choose those which he prefers. In those high myopes who are over twenty years of age, a weaker glass for near work is found even more necessary than in the lower degrees of error. In the most pronounced cases, especially where much pathological change is present in the fundus, little benefit may be found to accrue from the use of any glass. Some of these patients are helped by compound telescopic spectacles, which reduce the field of vision but magnify considerably (see p. 379); while others appear to get about more comfortably unaided. In attempting to look at near objects, they see most efficiently by neglecting the worse eye, and relying upon the better alone, in which case they bring the object close up to the eye in order that they may obtain the benefit of an enlarged image.

In all cases, when lenses of considerable power are used, a great deal of attention must be paid to the proper fitting

Digitized by Illinois College of Optometry Library

of the glasses themselves (see p. 353), for a small amount of decentring brings about marked astigmatic and prismatic effects. For this reason, in order to avoid looking obliquely through their glasses, these people get into the habit of turning the head rather than the eyes, and their useful field of vision is therefore considerably curtailed. This prismatic effect can, however, be taken advantage of to a limited degree to relieve the anomalies of muscular balance which are so frequently found. In most cases the comfort of the glasses is considerably enhanced if a slightly tinted material is used, such as Crookes' A or "soft-lite." These bring much relief by diminishing the irritation caused by the small bright images formed upon the retina. The weight and thickness of strong glasses is another source of trouble, but this can be overcome to some extent by using flint glass, which has a higher refractive index than ordinary crown glass. The double advantage of lightness and a uniform tint is gained by the recent "soft-lite thin-lite" lenses (see p. 374).

Finally, in all cases, and especially in the young, it is to be remembered that the condition is potentially progressive, and is always to be regarded as such until time has shown it to be stationary. It is essential that all young patients be examined at intervals of six or twelve months; for the keeping of their optical error continually corrected is the most efficient method within our knowledge of retarding the progress of their disease.

The *general hygienic treatment* is no less important than the provision of glasses. Particularly is this the case in children. The general health should be built up with tonics and an abundance of fresh air and exercise. Near work should be rigidly restricted, and the education conducted on rational rather than traditional lines. School hours should be short, and study should be interpolated with rest intervals, when physical exercise should be enjoyed, and on the first onset of fatigue all work should cease abruptly. Attention should be paid to ventilation, to illumination, to posture, and to

Digitized by Illinois College of Optometry Library

the suitability of the books employed. Convalescence from illness should be prolonged, and on any evidence of rapidly increasing myopia, school should be abandoned incontinently, and a complete holiday in the country for a year or more should be enforced. Similar considerations should be applied to adults, modified to meet the requirements of their case and their economic circumstances.

Where the condition is already advanced and education becomes an economic necessity, the child should be sent to a school where educational methods suitable to his condition are undertaken. Of the methods to be used in establishments dealing with the difficult problem of educating such children, those adopted by the London County Council in their "myope classes" provide an admirable example. An attempt is made as far as possible to provide individual tuition in a curriculum where the cultivation of associative memory is made the first consideration, and where the sense of touch is relied upon more than sight. Models which can be handled are used in place of pictures, and oral tuition takes the place of reading out of books, while the eyes are used only for bold blackboard drawings and for large-typed and well-spaced printing. In all these children an out-door interest should be studiously cultivated to the exclusion of the indoor interest of books and figures, and an avocation suitable to their disability should be strongly encouraged.

An *operative treatment* for myopia, suggested by Boerhaave in 1708, was popularised by Fukala (1889). We have seen that the aphakic eye is normally strongly hypermetropic. If an eye with an axial myopia of $-$ 24 D. is deprived of its lens it will become emmetropic without any correcting glass, inasmuch as parallel rays of light will be focused upon the retina. The retinal images, moreover, will be larger than in emmetropia, but, at the same time, it must be remembered that all accommodation will be abolished. It has to be borne in mind also that the highly myopic eye is a diseased eye, and is by no means an ideal one to withstand operative procedures. The two main dangers from which complications may arise are the fluidity of the vitreous and the predisposition to retinal detachment.

Digitized by Illinois College of Optometry Library

Operation, therefore, should not be lightly undertaken, and nothing but the simplest procedures should be contemplated. Simple discission only should be practised, without subsequent curette evacuation, unless it becomes imperative on account of raised tension. It should only be done upon one eye, the other being held in reserve; and it should only be done when the patient is young, when his fundus is healthy, and when a myopia of at least -20 D is present.

Digitized by Illinois College of Optometry Library

CHAPTER VII

ANOMALIES OF REFRACTION

3. Astigmatism

ASTIGMATISM (ἀ, privative; στίγμα, a point) is that condition of refraction wherein a point focus of light cannot be formed upon the retina. Theoretically, no eye is stigmatic, and in practice we include under this form of ametropia those anomalies in the optical mechanism wherein an appreciable error is caused by the unequal refraction of light in different meridians.

Sir Isaac Newton, who himself appears to have been astigmatic, first considered the question of astigmatism in 1727. This optical error received its first detailed investigation from that many-sided scientist, Thomas Young, in 1801; he had 1·7 D of astigmatism, and since it remained on his immersing his head in water and thus eliminating the influence of the corneal refraction, he attributed his defect to the lens. The Cambridge astronomer, Airy (1827), was the first to correct the defect by a cylindrical lens; but it was largely the work of Donders (1864) which impressed the ophthalmological world with the prevalence and importance of this anomaly.

Ætiology.—Astigmatism may either be an error of curvature, of centring, or of refractive index.

Curvature astigmatism, if of any high degree, has its seat most frequently in the *cornea*. The anomaly is usually congenital, and ophthalmometric measurements show that its occurrence in small degrees is almost invariable. The most common error is one wherein the vertical curve is greater than the horizontal (about 0·25 D); this is accepted as physiological, and is presumably due to the pressure of the upper lid upon the eye. There is evidence that it tends to increase to a very slight extent with advancing years.

Digitized by Illinois College of Optometry Library

Developmental defects of a higher order are extremely common and are very frequently associated with hypermetropia: it is rare, indeed, for this latter condition to occur as a spherical defect. The deformation of the eye-ball in axial myopia also frequently involves an astigmatic complication.

An acquired astigmatism is not infrequently seen. Disease of the cornea results in its deformity; an extreme example of this is seen in conical cornea, while inflammations and ulcerations produce the same effect. Traumatic interference with the cornea, as after operations involving a corneal section, bring about the same result; and it may be seen to a lesser degree after a tenotomy. Finally, corneal astigmatism can be induced by the pressure of tumours of the lids, or a transient deviation from normal can be produced by finger-pressure on the eye, by contraction of the lids, or by the action of the extra-ocular muscles.

Curvature astigmatism of the *lens* also occurs with great frequency; and as its effect may either accentuate or neutralise the corneal curvature, those methods of correcting astigmatism, such as the ophthalmometer, which investigate the corneal curvature only, are completely untrustworthy except in cases of aphakia. In the great majority of cases such anomalies are small; but on occasion, as in lenticonus, they may be extremely marked. Not uncommonly the lens is placed slightly obliquely, or out of line in the optical system (see p. 68), and this, causing a certain amount of *decentring*, produces a corresponding astigmatism: a traumatic subluxation of the lens has similar results. Finally, a small amount of *index astigmatism* occurs physiologically in the lens. This is usually slight, and is due to small inequalities in the refractive index of the different sectors, but it may be accentuated to produce extreme distortion or even polyopia in the grosser changes of cataract.

There has been a very great deal written, dating from the time of Dobrowolski (1868), but more especially within recent years,

Digitized by Illinois College of Optometry Library

about the so-called *dynamic lenticular astigmatism* and its supposed deleterious effects. An unequal contraction of the ciliary muscle is said to induce forcibly a deformation of the lens which tends to neutralise the corneal astigmatism, and in so doing involves, immediately, the most severe and far-reaching symptoms of eye-strain, and eventually becomes a very potent factor in the causation of cataract. There is no scientific foundation for such a claim. It is based upon the experimental work of Hensen and Voelckers, who showed that when a filament of the ciliary nerve was divided, a local contraction of that part of the ciliary muscle supplied by the filament can be induced. But this will occur if the local nerve supply of any muscle mass is separately stimulated, and such an isolated contraction under experimental conditions bears no relation at all to the normal action of the muscle in life. The clinical evidence adduced in its favour is based upon the fact that a different astigmatic refraction is found before and after paralysis of the ciliary muscle by atropine, the difference, it is claimed, being due to the deformation produced by unequal ciliary contraction. Even the most enthusiastic supporters of the theory admit that such a difference is limited in degree to 0·5 D or less, and a difference of this magnitude can quite well be accounted for by the great change in the optical system which a variation in the pupillary diameter may bring about. Further, the curvature of the lens is demonstrably different in the relaxed condition of cycloplegia and in the strained condition maintained by the normal tone of the ciliary muscle. When there is no ciliary spasm it seems to follow that the physiological curvature of the lens is more correctly measured in the absence of a cycloplegic than with it. In any case, the observations of the most reputable workers in this field strongly oppose this conception of an unequal ciliary contraction, a point of agreement even among those of totally different schools of thought, such as Tscherning and Hess; and all the evidence goes to show that if any part of the ciliary muscle contracts in life, it contracts equally all round, and if one muscle contracts the muscle in the opposite eye acts equally and simultaneously in all ordinary conditions.

Optical Condition.—The manner of the refraction of parallel rays of light by an astigmatic system has already been described (p. 46); sections of the beam so formed are repeated here (Fig. 67), for ease of description. If A represents a circular beam before refraction, it is seen that at no point is a sharp focus obtained; at one point (C) an elongated vertical image is produced because the beam is in focus horizontally, at another an elongated horizontal image is

Digitized by Illinois College of Optometry Library

produced (E) since the vertical plane of the beam is brought to a focus, at a point between these two (D) a circle of least diffusion is formed where the deviations from focus act equally throughout, while in any other position (B, F) a greater or less degree of distortion is produced. Instead of a single focal point, there are two *focal lines* (C and E), separated from each other by a *focal interval.* The length of this focal interval is a measure of the degree of astigmatism, and the correction of the error can only be accomplished by reducing these two foci into one. It will be remembered that a cylindrical lens refracts rays of light in one plane, and leaves unaltered the rays in the plane perpendicular to

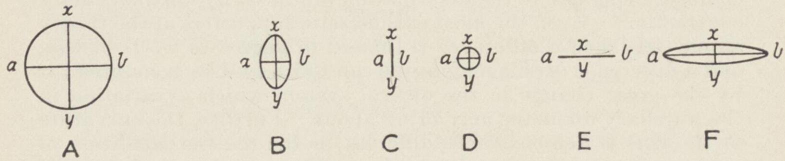


FIG. 67.—AN ASTIGMATIC BEAM.

A, a circular refracting body of which the vertical meridian (xy) is less curved than the horizontal (ab); at B, a vertical ellipse is formed; at C, a vertical straight line is formed; at D, a circle (of least diffusion) is formed; at E, a horizontal straight line is formed; at F a horizontal ellipse is formed; C and E are focal lines, and CE is the focal interval.

this (that is, in the plane of its axis). If the two principal meridians of the astigmatic system are at right angles to each other, the error can therefore be corrected by the use of a suitable cylindrical lens, which, acting in the plane of one meridian, so changes the refraction of the rays that they are brought to a focus at the same distance as those of the other meridian, in which case the whole image (theoretically) becomes a point.

Types of Astigmatism.—This type of astigmatism, where the two principal meridians are at right angles and which is therefore susceptible of correction, is called *regular astigmatism.* When the axes are not at right angles but are crossed

Digitized by Illinois College of Optometry Library

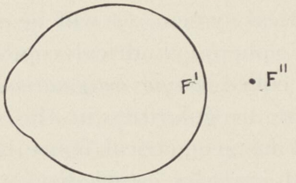


Fig. 68.—Simple Hypermetropic Astigmatism.

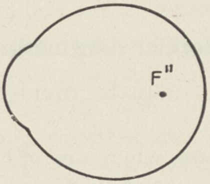


Fig. 69.—Simple Myopic Astigmatism.

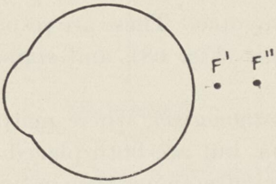


Fig. 70.—Compound Hypermetropic Astigmatism.

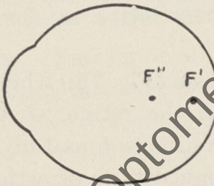


Fig. 71.—Compound Myopic Astigmatism.

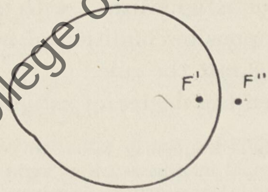


Fig. 72.—Mixed Astigmatism.

Digitized by Illinois College of Optometry Library

obliquely, the optical system, as will be seen later, is still resolvable into a sphero-cylindrical combination, and the condition may be called *oblique astigmatism*.[1]

Where there are irregularities in the curvature of the meridians so that no geometrical figure is adhered to, the condition is called *irregular astigmatism*; it does not lend itself to adequate correction.

Regular Astigmatism

Regular astigmatism may be divided into the following sub-divisions:

(1) *Simple astigmatism*, where one of the foci falls upon the retina. The other focus may fall in front or behind the retina, so that while one meridian is emmetropic, the other is either hypermetropic or myopic. These are respectively designated *simple hypermetropic* (Fig. 68), and *simple myopic astigmatism* (Fig. 69).

(2) *Compound astigmatism*, where neither of the two foci lies upon the retina, but are both placed in front or behind it. The state of the refraction is then entirely hypermetropic, or entirely myopic. The former is known as *compound hypermetropic* (Fig. 70), the latter as *compound myopic astigmatism* (Fig. 71).

(3) *Mixed astigmatism* (Fig. 72), where one focus is in front and the other behind the retina, so that the refraction is hypermetropic in one direction and myopic in the other.

The usual physiological type of astigmatism, wherein the vertical curve is greater than the horizontal, is termed *direct astigmatism*, or astigmatism "with the rule," in contradistinction to the opposite condition of *indirect astigmatism*, or astigmatism "against the rule."

Symptoms.—When the degree of astigmatism is small, the

[1] Oblique astigmatism is frequently taken to connote a regular astigmatism where the principal meridians are at right angles, but instead of being vertical and horizontal, or nearly so, as is usually the case, are inclined at an angle approaching 45° from these directions.

Digitized by Illinois College of Optometry Library

visual symptoms may be *nil*, and the acuity of vision may be normal. When the error is of appreciable size, however, since in no circumstances can the eye form a sharply-defined image upon the retina, the diminution of visual acuity may be very considerable. In his endeavour to see clearly the patient attempts to focus, not the central circle of least diffusion, but one or other of the focal lines. Other things being equal, the meridian which approaches most nearly the emmetropic condition is chosen, and if the two are approximately equally in error, the vertical focal line is as a rule preferentially sought after. This is a natural adaptation, for it will be found in practice that most objects, and certainly printed matter, are least indecipherable when they

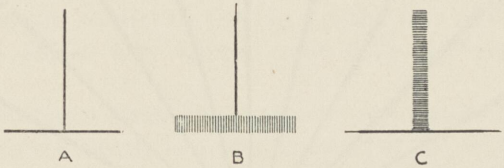


Fig. 73.—Vision in Astigmatism.

A, two lines as seen by a normal eye ; B, appearance to an astigmatic eye with the horizontal meridian corrected ; C, appearance to an astigmatic eye with the vertical meridian corrected.

are distorted vertically. Since a focal line is made the object of attention, the vision of the astigmatic shows peculiarities other than indistinctness on account of the elongated form of the diffusion circles which he has to interpret. Circles become elongated into ovals ; a point of light appears tailed off ; and a line, which consists of a series of points, appears as a succession of strokes fused into a blurred image. Let us imagine an astigmatic person focusing on the vertical focal line (C, Fig. 67), and looking at two straight lines (A, Fig. 73), standing the one perpendicular to the other. We may imagine the lines made up of an infinite number of points, each of which appears on his retina as a short vertical stroke (or, more correctly, an ellipse). The horizontal line therefore

Digitized by Illinois College of Optometry Library

appears as a series of such vertical strokes which coalesce into a broad blurred band (B, Fig. 73), while in the case of the vertical line, the vertical strokes are superimposed and cover each other, so that the whole line appears sharply defined, with only the uppermost and lowermost of the constituent strokes extending beyond it, giving it a tailed-off appearance and making it seem longer than it really is. Conversely, if the horizontal focal line (E, Fig. 67) is focused, the vertical lines become blurred (C, Fig 73). Thus

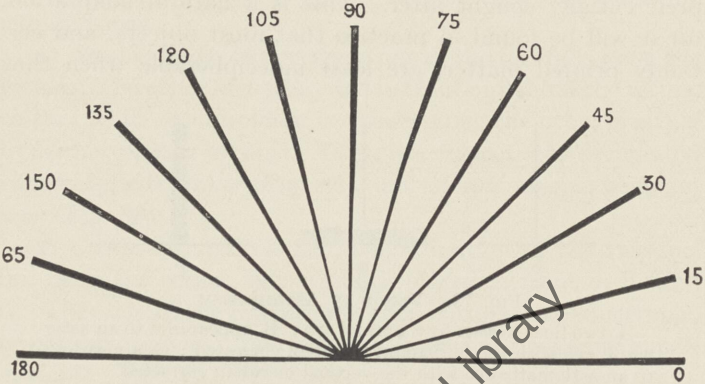


Fig. 74.—The Astigmatic Fan.

in every case of regular astigmatism there is one direction in which lines appear most distinct, and one in which they appear most confused. This is taken advantage of in the detection of astigmatism by a fan-shaped figure (Fig. 74). On looking at such a figure, if any of the lines are seen more clearly than the others, astigmatism must be present; if the vertical lines are clear, the diffusion ellipses on the retina must be vertical, that is, the horizontal meridian must be more nearly emmetropic than the vertical. A cylinder placed in front of the eye with its axis horizontal will therefore correct the vertical meridian, and when the correct glass is found all the lines will appear equally distinct. The cylinder

Digitized by Illinois College of Optometry Library

which thus renders the outline of the whole fan equally clear is a measure of the amount of astigmatism, and the axis of the cylinder is at right angles to the line which was initially the most clearly defined.

These anomalies of vision produce errors of confusion in reading letters. No two lines at right angles can appear equally clear, an L, for example, may have its horizontal limb blurred and its vertical limb sharply defined. From their form certain letters appear specially confusing: H and N; B and S; F, P and R; W and M; K and X; V and Y, and so on, and mistakes are readily make in reading them. If the axis of the cylinder is oblique, the head is frequently held to one side so as to reduce the distortion; and in all cases there is a tendency to half-close the lids in order to make a stenopaeic slit, so that by cutting out the rays of one meridian, the object may appear more distinct though more faint.

The continuous strain thrown upon accommodation in the attempt to see clearly is a prolific cause of the *symptoms of asthenopia and eye-strain* of the most marked degree. Particularly is this so in the case of small astigmatic errors, for here the measure of success which the accommodative effort achieves, stimulates it to greater endeavour. Thus, as we have seen in an earlier chapter, the most marked symptoms are associated with the greatest retention of visual acuity, and where the error is so gross as to make any correcting effort useless, none is made and visual symptoms only are evident. It has already been noted that in the great majority of cases these small errors give rise to no discomfort; they may be accepted as physiological, and do not require treatment. In other cases, however, all the symptoms already considered under the subject of eye-strain may be present: headaches varying from a mild frontal ache to violent explosions of pain, dizziness, neurasthenia, irritability, fatigue, and a whole gamut of reflex nervous disturbances. The most severe symptoms are usually seen in cases of hyper-

Digitized by Illinois College of Optometry Library

metropic astigmatism, where the accommodation is called upon to make further efforts to overcome the hypermetropia ; and it is always to be remembered that the greatest distress tends to occur most typically in those whose defect is so small that their eye-sight appears to be good beyond suspicion.

The eyes themselves frequently suffer from fatigue and temporary obscurations of vision, and objects and printed words appear to dance about more frequently than in other refractive errors. The strain brings on congestion with conjunctivitis and blepharitis ; the characteristic appearance of the eyes is accentuated by the half-closed lids ; while the tilting of the head and shoulders may become a habit, leading to the development of scoliosis in young subjects.

Most authorities state that in the estimation of astigmatic errors in persons below forty years of age a cycloplegic should be invariably used ; and some insist that the smallest amount of astigmatism found under these conditions—even errors of the order of $\frac{1}{8}$ of a dioptre—should be rigorously corrected. This teaching, however, takes no cognisance of the fact that the optical system under mydriasis and cycloplegia is by no means the same as when in the normal condition. The question will be dealt with more fully when considering the use of cycloplegics in general, and mention will be made here of only one fact. It has been amply demonstrated that the form of the lens when relaxed under atropine is completely different from that found in the accommodated or partially accommodated state ; in the latter a considerable lenticonus is formed by the anterior surface. When the physiological tone of the ciliary muscle is active, as it is normally, $\frac{1}{8}$ of a dioptre as found under atropine, will certainly not remain as such ; and it is the astigmatism which is present under normal conditions that we wish to correct. In all cases below the age of twenty a cycloplegic should properly be used because of the considerable dynamic influence of the ciliary muscle at this age, and whenever over-activity or spasm or strain of the ciliary muscle is suspected in persons between the age

Digitized by Illinois College of Optometry Library

of twenty and forty-five, the same procedure certainly should be adopted. Apart from these, its necessity or advisability depends upon the symptoms of the patient, on the optical facilities for estimating the refraction, on the skill of the refractionist, and on the time at his disposal. When a cycloplegic is used the patient should, if possible, be seen again after the effect of the mydriatic has worn off, and the vision again tested with the correction previously found, deducting a suitable amount to allow for the ciliary tone. But if an alteration in the strength or in the axis of the cylinder gives an appreciable improvement of vision, the final glasses should be modified accordingly, cases of ciliary spasm being treated on the lines indicated in discussing hypermetropia.

Finally, since a certain amount of lenticular astigmatism is so common as to be the rule, any ophthalmometer which measures only the corneal curvature can give little indication of the actual refraction of the dioptric system of the eye considered as a whole. Especially in the estimation of small errors such an instrument is useless.

Treatment.—Provided they produce no deterioration of the visual acuity, and provided they are giving rise to no symptoms of asthenopia and eye-strain, the smaller astigmatic effects do not require correction ; but if any of these two conditions are present, an error, no matter how small, should receive attention. Especially is this so when symptoms of eye-strain are present, and the great importance of small errors in this respect should always be remembered. In such cases also the glasses should be advised for constant use. It is obvious that in the correction of these small errors the utmost care is to be exercised, for any difference that remains is left for the patient to attempt to correct, and if he is forced to do this the symptoms of asthenopia may continue or even be exaggerated.

As has been noted before, the difference between the refraction of the two principal meridians represents the amount of astigmatism, and the refraction of the lower meridian repre-

Digitized by Illinois College of Optometry Library

sents the spherical correction with which the cylinder is to be combined. As a rule, every attempt should be made to correct the cylindrical defect fully, and this applies with more force when a complaint of eye-strain is made. It sometimes happens, however, that in adults with high errors who have never worn glasses, the unaccustomed effect of cylinders of considerable power makes objects appear distorted and causes much distress, and in these it may be well to under-correct the error until they have become used to them, when at a later date, the full correction may be worn comfortably. The spherical correction should be treated on the lines indicated when discussing hypermetropia and myopia. Where eye-strain is evident, the full correction should be tried in all cases ; where it is absent, myopia should be corrected fully except when it is of great amount, and in hypermetropia the strongest lens which gives maximal visual acuity should be ordered, giving an additional correction for near work if required.

Oblique Astigmatism

When the axes of the two principal meridians are not at right angles to each other, but are obliquely crossed, they cannot be corrected by sphero-cylindrical glasses as such. Such a combination, however, can always be resolved into another equivalent combination in which the two axes are at right angles, and which is thus susceptible of optical correction. That this is so can be readily seen if two cylindrical glasses be taken from the trial case and held with their axes at various angles before a small point of light ; it will be seen that in all positions of the lenses, the optical effect is the production of two focal lines at right angles to one another. These, of course, can be exactly reproduced by a pair of cylinders at right angles, or by an ordinary sphero-cylindrical combination.

Professor Thompson has indicated a neat graphic method

Digitized by Illinois College of Optometry Library

by which the result can be obtained. Having found the strength of the refraction in the two meridians and the angle at which they are inclined, we draw a line OA (Fig. 75) on any agreed scale to represent the one of them of greater power, and OB to represent the other of less power, so that the angle AOB is twice the angle between their axes. Then, on completing the parallelogram, the diagonal OC represents the strength of the resultant cylinder, and the angle COA represents twice the angle at which it is inclined to the meridian of greater power (OA). For positive cylinders the directions OA and OB are chosen; for negative cylinders, the opposite directions. The actual value of these can easily

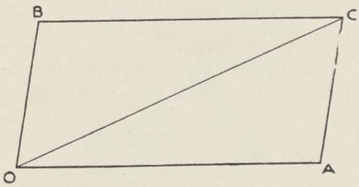


Fig. 75.

be obtained by measurement to scale. Since the sum of the refractive powers of the original combination must equal that of the resultant combination, the strength of the spherical component of the new system can easily be deduced from a simple formula.

An example will make this clear. Suppose in the refraction we find that there are two principal meridians inclined to one another at an angle obliquely. Let us represent these by F_1, which is + 4 D, and which lies at an axis of 20°, and F_2, which is + 2 D inclined at an axis of 60°. We then draw to scale, OA = 4, OB = 2, and angle BOA, which is twice the angle between them (*i.e.*, twice 40°), 80°. Then on completing the parallelogram, the resultant cylinder, C, is found on measurement to be 4·7 D and the angle COA 24°. The required cylinder, therefore, lies inclined at an angle of 12° to the direction of F_1, that is, at an angle of 32° in the accepted notation.

This cylinder must be combined with a sphere, which we may

9—2

Digitized by Illinois College of Optometry Library

denote S, and, therefore, in the combination, the curvature of the meridian of minimum power will be S dioptres, while that of the maximum will be S + C dioptres. Since the sum of the powers of the new combination must equal that of the old, we can obtain the value of this sphere from the formula :—

$$S + (S + C) = F_1 + F_2$$
$$2S + C = F_1 + F_2$$
$$S = \frac{F_1 + F_2 - C}{2}$$
$$= \frac{4 + 2 - 4{\cdot}7}{2}$$
$$= 0{\cdot}615 \text{ dioptre.}$$

Instead of the graphic construction, the values of the cylinder and the direction of its axis can be found from the following formula derived by Thompson (*Phil. Mag.*, March, 1900).

Where a is the angle included between the axes of the two meridians, and β is the angle included between the axis of F_1 and of the resultant cylinder C,

then C is given by :—

$$C = \sqrt{F_1{}^2 + F_2{}^2 + 2\,F_1F_2 \cos 2a}$$

Where θ is the angle at which the required cylinder lies with reference to F_1,

$$\tan 2\theta = \frac{F_2 \sin 2a}{F_2 + F_1 \cos 2a}$$

Thus in the example give above, where $F_1 = 4$, $F_2 = 2$, and $a = 40°$,

$$C = \sqrt{16 + 4 + 2 \times 4 \times 2\,(0{\cdot}1736)} = 4{\cdot}77$$

and $$\tan 2\theta = \frac{2 \times 0{\cdot}9848}{4 + 2 \times 0{\cdot}1736} = 0{\cdot}453.$$

$$\therefore\ \theta = 12°\,12'.$$

That is, expressed to the nearest $\frac{1}{8}$ dioptre, the original combination of obliquely crossed cylinders,

$$+ \text{ 4 D cyl. ax. } 20° + \text{ 2 D cyl. ax. } 60°$$

is optically equivalent to

$$+ \text{ 0·62 D sph. } + \text{ 4·75 D cyl. ax. } 32°.$$

In this form a lens can be ground, and as such it should be ordered, small alterations being made, if necessary, in the axis and the strength of the sphere in order to get the maximum comfort and visual acuity.

Emsley (*Proc. Optical Convention*, 1926) has simplified the practical application of these formulæ by tabulating the values for a large number of combinations and constructing a graph from them, from which the strength of the resultant cylinder,

Digitized by Illinois College of Optometry Library

and the direction of its axis, can be read off directly. He has also suggested an ingenious instrument which consists of two rotating protractors, by means of which such transpositions can be done with great rapidity and ease.

Irregular Astigmatism

In irregular astigmatism the refraction in different meridians is quite irregular. A small degree of this defect occurs physiologically owing to minute differences in the refractive index of the lens ; but its effect is so small as to be inappreciable. It is only when the difference in the refractivity is

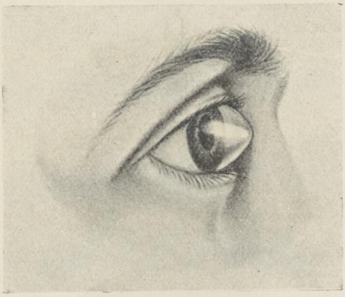


Fig. 76.—Conical Cornea.

accentuated, as in incipient cataract, that symptoms are caused ; indeed, in this condition the distortion may be so great as to lead to polyopia.

A marked degree of irregular astigmatism is commonly found only in pathological conditions of the cornea, when it is the result of irregular healing after traumata, inflammation, or ulcerating processes. In any of these cases the visual defect caused by the optical error is accentuated by the presence of opacities, and the combination of the two makes any attempt to improve vision by glasses frequently very difficult or impossible.

A rarer condition is *conical cornea* (*kerato-conus*) (Fig. 76). Probably owing to congenital weakness rendered apparent

Digitized by Illinois College of Optometry Library

by exhausting illness or debility in later life, the cornea is bulged forwards by the intra-ocular pressure into the shape of

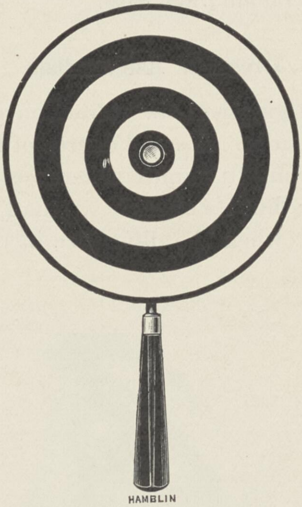


FIG. 77.—PLACIDO'S DISC.

FIG. 78.—THE RINGS OF A PLACIDO'S DISC AS DISTORTED IN THE REFLECTION OF A CONICAL CORNEA.

a cone, the apex being slightly below the centre. The eye becomes myopic, but owing to the hyperbolic nature of the curvature, the refraction is irregular. The difficulties of adequate correction are increased by the fact that the condi-

Digitized by Illinois College of Optometry Library

tion is progressive, and the optical conditions tend constantly to change.

The condition is most easily recognised by observing the distortion of the corneal reflex. This is best done by holding up a large flat disc painted with concentric black-and-white circles

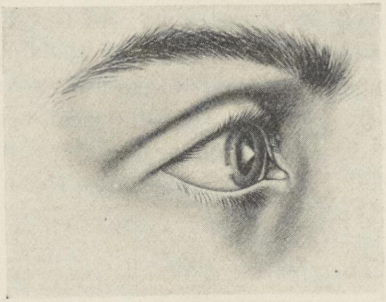


FIG. 79.—ANTERIOR LENTICONUS.

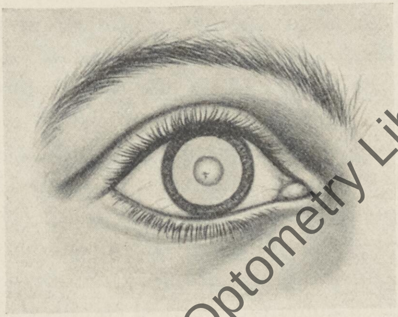


FIG. 80.—THE OPHTHALMOSCOPIC APPEARANCE OF LENTICONUS.

(Placido's disc or keratoscope, Fig. 77) in front of the eye; the reflex is observed through a hole in the centre of the disc, and the distortion of the circles is readily appreciated (Fig. 78). When the eye is examined with the ophthalmoscopic mirror at 1 metre distance, a ring shadow is seen in the red reflex of the fundus, which alters its position on moving the mirror. This ring appears dark because none of the rays from the fundus passing through it enter the observer's eye, the rays on the central side being convergent, and those on the peripheral side being divergent.

Digitized by Illinois College of Optometry Library

A condition of somewhat the same nature is seen in *lenticonus* (Fig. 79). This is due to a similar deformation of the curvature of the anterior or posterior surface of the lens or of the configuration of its nucleus. It is a rare congenital anomaly whose precise origin is in doubt. The centre of the pupillary aperture has a myopic refraction, while the periphery is relatively hypermetropic, and the difference may be so great as to make two images of the fundus possible. Ophthalmoscopically, a dark disc is seen situated in the centre of the pupillary aperture, resembling in appearance the effect produced by an oil-globule in water; its appearance is due to the same optical phenomena as the similar zone in conical cornea (Fig. 80).

Treatment.—The treatment of all these varieties of irregular astigmatism is difficult, and at best unsatisfactory. Conforming to no optical system, their refraction must be estimated largely by a method of trial and error, a process which absorbs a large amount of time and patience and frequently leads to no satisfactory result. Usually some astigmatism is obvious, and its nature may form a basis on which to start. The most useful procedure is probably to use a stenopaeic slit, and, moving it round to that meridian at which best vision is obtained, to correct this as far as possible by spherical lenses until no further improvement can be obtained. Then, turning the slit round at right angles, the same procedure is gone through; and by combining the two results into a sphero-cylindrical combination, a starting point is obtained for further attempts at improvement.

The improvement which can be obtained will frequently be found to be disappointingly small; but considerable care should be expended in the attempt, if only because little benefit can be hoped from other means. In some cases operative measures may be indicated. For example, a thin translucent nebula situated in the centre of the pupillary area may be benefited by being made quite opaque by tatoo-

Digitized by Illinois College of Optometry Library

ing with ink or gold chloride. In the former case light is allowed to pass through, and as it traverses the nebula it is refracted irregularly and renders the whole retinal image blurred; but a complete opacity allows the passage of no rays, and since the rays from the periphery can reach the part of the retina directly behind the blocked-out area in the cornea, a more clearly defined, although fainter, image may be formed (Fig. 81). Again, an optical iridectomy may improve vision when there is an opaque central cornea and

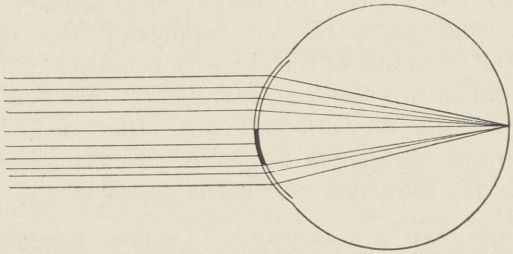


FIG. 81.—THE EFFECT OF A DENSE CORNEAL OPACITY.

The effect of such an opacity is to cut off completely all the rays incident upon it. The area of the retina behind the opacity is reached by rays coming in through the more peripheral parts of the cornea.

a clear periphery; a cauterisation of the tip of the cone may stay the progress of a conical cornea; or a discission of the lens may place a patient with lenticonus in a much more comfortable condition by rendering him aphakic. If these operative methods are not available, recourse, in the end, may be had to the use of stenopaeic spectacles, or telescopic glasses, or one of these ingenious devices, such as the hydrodiascope or the contact glass, may be tried. These last are little if at all known in this country, but in cases of conical cornea, where the media are still clear, although their use is not unassociated with disadvantages, the improvement they produce may be extraordinary. Mention will be made of them subsequently in more detail (see p. 381).

Digitized by Illinois College of Optometry Library

CHAPTER VIII

ANOMALIES OF REFRACTION

4. Anisometropia

Anisometropia (ἀ, privative; ἴσος, equal; μέτρον, measure; ὤψ, eye) is the term applied to that condition wherein the refraction of the two eyes is unequal. The condition is found in every possible variety: one eye may be emmetropic and the other of any other denomination, hypermetropic, myopic, or astigmatic, or both eyes may be ametropic, the refraction differing in degree or also in kind.

In America there is a suggestion to confine the term *anisometropia* to that condition wherein there is a different degree of refraction of the same kind in either eye, and to use the term *antimetropia* where the refraction differs in kind, one eye, for example, being hypermetropic, and the other emmetropic or myopic.

Anisometropia is extremely common in small amount, especially where astigmatic errors are present. The recession of hypermetropia and the progress of myopia are frequently unequal, the latter especially giving rise to large degrees of anisometropia. Apart from this and the refractive disturbances caused by the traumata of operations and disease, the condition is usually congenital, and is as a rule associated with a varying degree of developmental asymmetry of the face. An absolutely isometropic refraction is as rare as a perfectly symmetrical face.

Vision in Anisometropia.—The vision in anisometropia may be affected in one of three ways; it may be binocular, it may be alternating, or it may be exclusively uniocular.

Binocular vision is the rule in the smaller degrees of the

Digitized by Illinois College of Optometry Library

defect, although it has been reported with a difference as high as 6 dioptres. Since the power of accommodation acts equally in both eyes and is not dissociated, the image of one eye is always blurred, but the patient, superimposing the indistinct image upon the distinct one, combines the two and obtains a stereoscopic effect. In these circumstances binocular vision is rarely perfect; and the attempt at fusion frequently, although by no means always, brings on symptoms of accommodative asthenopia.

With the higher grades of error, fusion is impossible of realisation, and one of two alternatives offer themselves.

Alternating vision may result, in which case each of the two eyes is used one at a time. This is especially apt to occur when they both have good visual acuity, and when one is emmetropic or moderately hypermetropic and the other is myopic. In these circumstances the patient falls into the easy habit of using the former for distant vision and the latter for near work. In these circumstances he may be very comfortable, never having to use either his ciliary muscle or his internal rectus, the absence of muscular effort compensating for the loss of binocular vision.

On the other hand, if the defect in one eye is high, and more especially if its visual acuity is not good, it may be *excluded altogether from vision.* The other and better eye is alone relied upon and, if it is not so already, the defective eye tends to become *amblyopic;* later, if the condition is untreated, it may become divergent. This amblyopia from disuse (*amblyopia ex anopsia*) is in most cases a preventable condition, since useful vision may be retained if the error in the defective eye is corrected early enough in life, and the use of the eye is insisted upon at that time by suitable exercises with sufficient perseverance (see p. 244). In adults, however, treatment by glasses more often fails than not, the failure being possibly in part due to a true amblyopia, but more probably to defective receptivity of the higher centres.

Digitized by Illinois College of Optometry Library

The state of the vision may be determined by the use of a colour test derived from a suggestion of Snellen. The word FRIEND is hung up in illuminated letters so that the alternate letters are green and red—F, I, N are green, and R, E, D are red. A green glass is placed in front of one of the patient's eyes and a red one in front of the other, and since he can only see the green letters through the green glass and the red letters through the red, we can tell at once from what he reads whether or no he is using both together. If he reads FRIEND at once he has binocular vision; if he reads FIN or RED persistently he has uniocular vision with the eye which has the corresponding glass; if he reads now one, now the other, he has alternating vision (for distance).

Treatment.—As ametropia is never corrected by unequal contraction of the ciliary muscles, the provision of glasses is the only means of treatment. Theoretically, the ideal treatment would be the full correction of each eye in order to produce a distinct image on the retinæ of both. In practice, this course is satisfactory and usually advisable when dealing with small refractive differences, but in the case of the higher grades several difficulties present themselves which require attention.

When correcting glasses are placed at the anterior focal plane of the eye, it will be seen (p. 369) that there is no change in the size of the retinal image from that formed by the emmetropic eye. This plane is 15·7 mm. in front of the cornea; and in practice, if the glasses are placed farther from the eye than this, with a convex lens the retinal image is enlarged, while with a concave lens it is diminished, the difference in size becoming considerable in the higher grades of anisometropia. If the spectacles are nearer than this point, an opposite effect will be produced. Before the correction was made the discomfort caused by the unequal images may not have been great because one of them was blurred and therefore easily neglected; but now when they are both sharply defined and still unequal, they give rise to distress and their fusion may become difficult or impossible. Further, whenever the patient looks to the side through the periphery of the lens, a prismatic effect will be produced

Digitized by Illinois College of Optometry Library

(see p. 353), and when the difference between the glasses is great, since the distortion is different in the two eyes, it will materially enhance the discomfort. Finally, these anisometropic errors are frequently associated with anomalies of muscle balance, if not with actual squint. When one image was indistinct and blurred, little inconvenience may have been caused, but with two clearly-defined images and the muscular imbalance still remaining, the patient may be introduced for the first time to all the discomforts and annoyances of diplopia.

This being the case, it follows that the treatment of these subjects cannot be undertaken on empirical lines. Each case must be considered separately, attention being paid to the amount of discomfort and the disability from which the patient is suffering without correction, and the amount he is likely to experience with it, always bearing in mind the advantages of binocular vision, and the importance of retaining the potentialities of an eye for vision in case of future accidents to the other. Where possible, the ideal correction should be aimed at, and in many cases should at least be attempted before resort is made to other expedients. It is surprising how often correction will be tolerated and eventually comfortably borne and its advantages appreciated, after an initial period of a few weeks have been weathered.

The following guiding principles will be found to be useful :

In children (under the age of twelve) every attempt should be made to induce the full correction to be worn, the younger the child the more persistent should be the attempt, the easier it will prove, and the more successful will be the result. Where muscular imbalance is marked, exercises should be undertaken, and where a strabismus has developed the deviating eye should be practised alone. The methods employed will be spoken of in detail subsequently (see p. 244). They must be carried out with great perseverance if they are to meet with success, and even so, the result is often disappointing. True binocular vision may rarely be attained, but enough

Digitized by Illinois College of Optometry Library

vision may be saved to render the eye of use in case of damage or disease of the other, and the cosmetic effect may be considerable in that a squint may be diminished, or even on occasion abolished. In older patients such treatment is almost certain to fail.

In adults with small grades of anisometropia and any degree of binocular vision—certainly those with a difference of 2 D and generally up to 4 D—a determined attempt should be made to wear the full correction, and the glasses should be used constantly. Especially is this course indicated

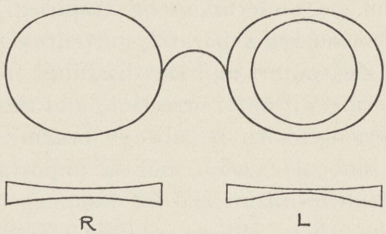


Fig. 82.—Anisometropic Glasses.

The right lens is corrected by —3 D sphere; the left by —6 D sphere. Peripheral aberrations may be much diminished if the central part only of the left lens is —6 D sphere, and the peripheral region is ground as a —3 D sphere. On looking to the side both eyes are thus subjected to the same degree of prismatic deviation.

where symptoms of eye-strain are present or muscular imbalance is evident. In these circumstances, after a few weeks' difficulty, the symptoms of strain will happily disappear. In older patients, however, it may be found that the correction involves headache and dizziness, and some compromise will be necessary. It is frequently advisable to under-correct the more ametropic eye, and a small deduction will often bring comfort; thus a patient who ought to have, but will not tolerate, a + 2 D and + 4 D sphere, may be happy with a + 2 D and + 3·5 D. Failing this, both eyes can be tried with the correction of the working eye, and it is usually the more emmetropic one (*i.e.*, + 2 D

Digitized by Illinois College of Optometry Library

and + 2 D). Similarly in myopia, the weaker one may be corrected, and a patient with — 2 D and — 4 D of error wearing glasses of — 2 D and — 2 D, will use the right eye for distant vision and the left for near work.

At the same time attention should be given to the correction of faults in muscle balance by prisms. In this way the occurrence of diplopia may be prevented. Where the difference between the two eyes is marked, the patient should be instructed to turn his head instead of his eyes in looking to the side in order to avoid the prismatic effect produced by the periphery of the lenses. This annoyance may be minimised by making the margin of the stronger lens weaker, so that it is equal to that of the other lens, as in Fig. 82, and thus, when the patient looks to the side, both eyes are corrected equally. This disturbing prismatic action of the periphery of lenses may be very evident in near work, for on looking down through the lower part of the lens, a convex lens acts as a prism base up and a concave one as a prism base down: this effect may be so marked as to result in diplopia. Where a myopic eye and a hypermetropic eye are thus associated, a certain amount of comfort in reading binocularly may sometimes be obtained on neutralising this action by cementing a correcting prism on to the lower portion of each lens: but in all of these cases it is wise to prescribe a separate pair of reading glasses carefully centred and tilted so that the visual axes in the reading position pass normally through them (see p. 359).

In an adult with alternating vision—one eye being hypermetropic and used for distance, and the other myopic and used for near work—unless there are definite symptoms of eye-strain, the condition is usually best left alone. If there are symptoms of eye-strain and the patient is young, an attempt may be made to induce him to wear the full correction. If this does not succeed, he should be provided with glasses which enable each eye to perform its separate

Digitized by Illinois College of Optometry Library

functions comfortably ; in most older cases this will be found the only useful plan to adopt. Where one eye has become definitely amblyopic in an adult, the good eye alone needs correction ; but where any useful vision remains in the other, it should receive regular exercises with the good eye occluded in order to preserve what function remains in case of eventualities.

Digitized by Illinois College of Optometry Library

CHAPTER IX

ANOMALIES OF REFRACTION

5. Aphakia

Aphakia (ἀ, privitive; φακὸς, the lens), although the term suggests an absence of the lens from the eye, is usually taken to embrace those conditions where the lens is absent from the pupillary area. In the vast majority of cases the lens has been removed by operation, sometimes it has been lost through a perforating wound or ulcer, it may be absent as a congenital defect, or it may be displaced from the pupil by dislocation.

The recognition of the condition is simple. Ordinarily, when a light is held before the eye obliquely, at least three distinct

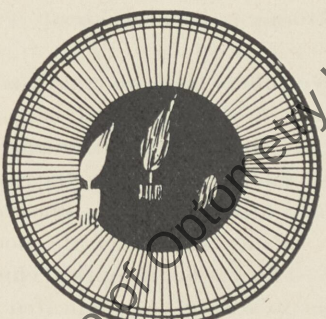


Fig. 83.—The Image seen by Reflection.

The clear image to the left is formed by the anterior corneal surface; the dim image in the centre is formed by the anterior surface of the lens; and the dim inverted image to the right is formed by the posterior surface of the lens.

images of it are seen by reflection at the surface of the cornea and the anterior and posterior surfaces of the lens (Fig. 83); in

Digitized by Illinois College of Optometry Library

aphakia the latter two are absent, and the corneal reflex alone remains. Further, on moving the eye there is apparent a characteristic tremulousness of the iris, which is now unsupported by the lens behind. The absence of the lens, moreover, usually leaves the anterior chamber very deep.

With the ophthalmoscope opacities may be seen in the pupillary area in cases of operative removal of a cataract, consisting largely of remnants of the lens capsule. If they are dense a needling operation may be required before attempting to estimate the refraction ; if they are slight, the advisability of such a procedure depends upon the vision which can be obtained with correcting glasses.

An aphakic eye is strongly hypermetropic ; in the absence of the lens, other things being normal, parallel rays of light are brought to a focus 31 mm. behind the cornea, while the average antero-posterior diameter of the eye is only 22·8 mm. The dioptric system must therefore be supplemented by a strong converging lens. If a glass lens were substituted for the crystalline lens so as to occupy the same position inside the eye, a strength of + 23 D would be required ; but inasmuch as it is placed about 14 mm. in front of the eye, a glass of much weaker power is equivalent. If the eye were originally emmetropic, a lens of about + 10 D is found necessary.

The aphakic eye suffers from several disadvantages which will be dealt with in greater detail later, but which are summarised here for the sake of convenience. Astigmatism, due to operative interference with the cornea, is almost invariably present : usually there is about + 2 D cylinder axis horizontal. Incidentally, since the nodal point of the eye has been moved forwards, the optical effect of the corneal curvature is never so strong as is indicated by the ophthalmometer. A gradual alteration in the curvature usually accompanies the changes occurring during the healing of the wound, and therefore glasses should not be prescribed until six weeks after the operation. All accommodation is abolished, and consequently the patient should theoretically be provided with a pair of glasses for every distance at which

Digitized by Illinois College of Optometry Library

he desires to see clearly. In practice it is usually sufficient to provide a glass for distant vision, one for reading distance, with in addition, in many cases, one for an intermediate position. A convex lens becomes stronger if it is removed away from the cornea (see p. 368), and so a certain amount of artificial accommodation may be attained by the patient if he moves the glasses up and down his nose, whereby his point of distinct vision is removed or brought nearer. A certain alteration in vision is also produced by contracting the pupils and so diminishing the circles of diffusion (see p. 76). These two circumstances form the only means available to compensate for the deficiency of accommodation; those claims which have been advanced for the possibility of an alteration in the corneal curvature by traction of the ciliary muscle have no basis on physiological fact.

Until the patient gets accustomed to the condition and has learned to make allowances for it, the lack of accommodation may cause a considerable amount of inconvenience. Thus he may get confused and expose himself to some risk under such conditions as piloting himself in traffic, working near rapidly moving machinery, stepping off pavements, or in going down stairs. Patients should always be warned of those facts, and their unavoidability should be explained. At the same time, in the great majority of cases it is surprising how well they are able to compensate for their defect after a little experience, although at the beginning great patience is often necessary to become accustomed to the new optical conditions.

The vision is rarely of normal standard. The optical conditions are completely changed, for the dioptric apparatus has been reduced to a single refracting surface (the cornea) bounding a medium of uniform refractive index (the aqueous and vitreous humours). The anterior principal focus, for example, is 23·27 mm. in front of the cornea. The result is that the image in the corrected lensless eye is about 24 per cent. larger than when the lens is present. The visual acuity is

Digitized by Illinois College of Optometry Library

therefore theoretically worse than is indicated by the usual clinical tests ; when vision is interpreted in visual angles, a vision of 6/9 in a corrected aphakic eye corresponds to an acuity of only 6/12 in an eye with its optical system unaltered.

Partly owing to the total lack of accommodation, and partly, and in greater measure, owing to the increased size of the retinal image, an aphakic eye can rarely be used in association with a normal one. Aphakia thus becomes an extreme and accentuated example of anisometropia. Consequently fusion of the two images is difficult or impossible, while the attempt to attain binocular vision usually results in diplopia, with its attendant embarrassments. For this reason, a patient with good visual acuity in one eye is little benefited by an extraction of a cataract in the other. Such an operation may be advisable in special circumstances : in the case of workmen, motor drivers, and others, it may be necessary to increase the visual field on the blind side ; or it may be advisable in order to prevent a cataractous lens from progressing to over-maturity, or in order to complete the operation before the age when a simple needling will not suffice, thus rendering the more serious operation of extraction unnecessary. But in these cases where a unilateral cataract is removed, it is rarely wise to attempt the correction of the aphakic eye by glasses.

Digitized by Illinois College of Optometry Library

CHAPTER X

CHANGES IN REFRACTION

ALTHOUGH, as a general rule, the refraction of a given eye is a relatively stable and constant quantity, there is always a tendency towards slow and gradual changes. These vary from time to time and from individual to individual; usually the changes are not great in degree, but their occurrence renders it necessary that the eyes should be examined and the glasses changed if necessary at periodic intervals.

Physiological Changes.—To a large extent these changes may be erratic, but there are certain well-defined tendencies of general occurrence which may be considered physiological. Most of these have already been alluded to in the previous chapters, and it will be sufficient here merely to recapitulate them. In the first place it will be remembered that at birth the average eye is hypermetropic; as growth proceeds it tends to become emmetropic; later this tendency may increase until a varying degree of myopia results. The first years of life are therefore a period of rapid transition until relative stability is reached at about the age of six or eight: the case of myopes, in whom the tendency is progressive until a later stage, or indefinitely, has already been described in detail.

Mention has also been made of the *apparent increase of hypermetropia* which accompanies advancing years and which indicates a decrease in the power of accommodation. As the lens becomes less plastic, that portion of the hypermetropia which was wont to be masked by an effort of accommodation gradually becomes less; the process is continuous throughout life, until at about the age of sixty

Digitized by Illinois College of Optometry Library

or sixty-five, the whole of the manifest hypermetropia has become absolute. The change, of course, is only apparent, for in the meantime the static refraction has remained unaltered. In addition to this apparent change, however, it will be remembered that a *change in the absolute refraction* also occurs with age. This is caused by a flattening of the concentric layers which make up the structure of the lens, and an increase of the index of refraction of the more peripheral ones in comparison with those more centrally placed, so that the effective index of the whole is decreased. Both processes tend towards the same direction and make the refraction slightly more hypermetropic. The tendency does not make itself definitely apparent until the fifth decade or later; its incidence is gradual and the total amount of change is slight; but eventually a hypermetropic error may increase by one or two dioptres or a myopic one may decrease by the same amount.

In astigmatism also there is frequently a tendency to gradual change. In a hypermetropic astigmatism the *axis tends to rotate* from a vertical direction towards the horizontal so that the vertical meridian becomes the more curved: in a myopic error the tendency is for a rotation of the axis of the cylinder in the opposite direction. This is by no means constant or invariable, and when it does occur, it usually involves a very slow transition of only one or two degrees a year.

Pathological Changes.—These changes which we have noted may be considered physiological: we have now to consider a group of changes of more dramatic occurrence which accompany disease. The first of these are *changes in the dynamic refraction* due to conditions of spasm or paralysis of the ciliary muscle. The effect is typically seen in the one dioptre of hypermetropia which is revealed by the ciliary paralysis following the instillation of atropine. The same effect is seen in those *nervous diseases* which affect the ciliary muscle similarly: the most typical is the paralysis of

Digitized by Illinois College of Optometry Library

accommodation frequently associated with encephalitis lethargica. *Trauma* to the eye-ball may act similarly, and many cases of transient refractive changes have been reported as a result of an accident involving a blow. The most common cause of the change is a paralysis or a spasm of the ciliary muscle, but a *displacement of the lens* backwards or forwards will have the same optical effect, while a subluxation and tilting of the lens will produce a marked degree of astigmatism. The myopia which accompanies spasm of the ciliary muscle is frequently met with in *iritis*, the spasm being due to the irritant effects of inflammatory products. The phenomenon is most evident in the plastic types of iritis, such as sympathetic disease, and it may be accompanied by gross disturbances of accommodation. It may give rise to the most variable visual effects, and in the course of an iritis a sudden decrease of vision may give rise to unnecessary alarm if a transitory myopic change is not suspected and allowance made for it.

A somewhat analogous change occurs in *glaucoma*. A slight degree of myopia may occur in the course of this disease, but it is neither common in incidence nor great in amount. This has been attributed to an increase in the antero-posterior diameter of the eye-ball due to the increase of intra-ocular tension ; but such a change can at most be slight. Only in the congenital condition of buphthalmia, when the pressure makes itself evident before the tissues are fully formed, is such an effect apparent to any marked degree: here, incidentally, the optical effect is largely neutralised by the depth of the anterior chamber and the relative displacement backwards of the lens. An increase of tension rarely stretches the dense adult sclerotic. When it does so, it usually acts by making the whole globe more spherical, and the diminution of the curvature of the cornea which this brings about is sufficient to produce the slight degree of hypermetropia which is occasionally observed in glaucoma. The shallow anterior chamber and the forward displacement

Digitized by Illinois College of Optometry Library

of the lens in the typical glaucoma of adults probably have a more marked influence in determining the myopic changes which are met with. After operation, for example, a trephining which leaves little complicating astigmatic deformity, the collapse of the anterior chamber invariably produces a marked myopia, and in the weeks following the operation the re-establishment of the chamber and the recession of the lens is accompanied by the gradual development of hypermetropia. A much more significant happening in glaucoma is a loss of accommodation, and this, occurring in an adult about middle life and after, makes itself evident as an early commencement or a rapid progression of presbyopia (see p. 179). The condition seems to be due to a pressure atrophy of the ciliary muscle, and its occurrence is a sign of some diagnostic importance.

Changes of refraction due to alteration in the shape of the coats of the eye are seen in an extreme degree after a *perforating injury or an operation.* After the anterior chamber has been re-formed there is a gradual transition stage which accompanies the contraction of the cicatricial tissue involved in the healing of the wound, a process which usually leaves a varying amount of permanent astigmatism. A similar deformity has been recorded following burns near the limbus. An artificial astigmatism may be produced by *pressure* upon the eye-ball such as can be produced experimentally by finger pressure upon the upper lid, or may result clinically from tumours situated here or in the orbit. Cases have been recorded wherein one or two dioptres of astigmatism have been produced in this way by a chalazion, and on the removal of the cause the refractive error has disappeared.

When the coats of the eye are diseased refractive changes are produced more readily. This is most obvious in *corneal disease,* such as ulceration or interstitial keratitis, when an irregular astigmatism usually results, a deformity largely cicatricial in nature. Softened by disease, the

Digitized by Illinois College of Optometry Library

cornea or sclerotic may gradually give way before the intra-ocular tension. A softening of the cornea may result in a progressive kerato-conus ; severe *scleritis* has been recorded as producing a considerable degree of myopia ; while a similar occurrence has been noted by such authorities as Knies, Priestley Smith, and de Schweinitz as forming a sequela of *choroiditis*. Myopia may also result from *constitutional disturbances* which may undermine the strength of the sclerotic. It has been noted accompanying dyscrasias of the pituitary gland, goitre, and obesity ; and it appears to form an occasional complication of such diseases as malaria and acutely debilitating illnesses such as the exanthemata.

Refractive changes of considerable importance are associated with alterations in the refractivity of the lens. The most common of these is the gradual myopic change which accompanies the early stages of *cataract*. It is due to the increase in the optical density of the lens which occurs in this disease, and is most evident when the nuclear parts are particularly involved. The most interesting and dramatic changes of this class, however, are those which occur very frequently in *diabetes*. These may occur with dramatic suddenness, and may involve alterations in refraction up to seven dioptres.

In the rising sugar-concentration of diabetes, provided the available water-reserve is maintained, the osmotic pressure of the aqueous tends to decrease, largely owing to the great elimination of osmotically active substances from the blood in the increased flow of relatively concentrated urine. The lens is a comparatively stable system, not readily participating in the fluctuations common to all the body fluids, and therefore it will tend to maintain its original molecular concentration ; consequently, in order to establish osmotic equilibrium, fluid tends to flow into it from the chambers of the eye. The lens therefore swells and is deformed, its curvature being increased ; further, the optical density of its peripheral layers becomes diminished while the nucleus

Digitized by Illinois College of Optometry Library

remains unaltered. On both counts its refractive power is increased, and the eye becomes myopic. If the process is sufficiently marked that the inflow of fluid is rapid, actual droplets are formed under the capsule of such a size that they can be seen by the slit-lamp, or even by the loupe; eventually a cataract may be formed, sometimes with great rapidity. Conversely, with a fall in sugar concentration, a reverse osmotic flow is inaugurated, and a condition of hypermetropia is produced.

A sudden and seemingly inexplicable myopia should thus always suggest the possibility of diabetes and direct attention to the urine; occurring in a known diabetic it should suggest a relapse in the progress of the disease. On the other hand, a sudden hypermetropic change, indicating, as it does, a general disturbance in the water-balance of the body, points to treatment being too suddenly undertaken or too rigorously applied: the condition has certainly become much more common since the general introduction of insulin in the treatment of this disease. In either case the treatment should not be directed to the eye but rather to the constitutional disease, for the refractive change is transitory and invariably returns to normal provided metabolic equilibrium can be re-established. If glasses are to be prescribed, they need be considered only as an emergent and temporary measure.

Digitized by Illinois College of Optometry Library

SECTION III

ACCOMMODATION AND CONVERGENCE

CHAPTER XI

ACCOMMODATION

Hitherto we have concerned ourselves mainly with the mechanism by means of which parallel rays of light are brought to a focus upon the sentient layer of the retina. We have seen that this is accomplished by the refractive system of the emmetropic eye without effort, and that, in conse-

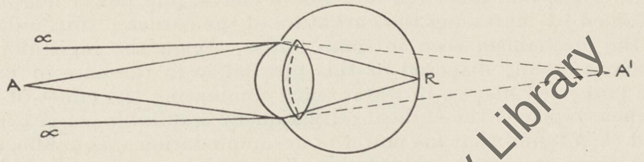


Fig. 84.—Accommodation.

In the emmetropic eye rays from infinity are brought to a focus upon the retina at R. When a near object, A, is looked at, a focus is formed behind the retina at A′ (the conjugate focus). In order to bring this focus forwards to R, the lens increases its convexity as illustrated.

quence, objects which are a considerable distance off are seen distinctly. It is obvious that if the eye is to function adequately, it must be able to vary its focus so that it can adapt its refractive mechanism to allow objects which are near at hand to be seen clearly. Thus in Fig. 84, parallel rays coming from an object (theoretically) infinitely far away are focused upon the retina; if the object is brought nearer (to A), the image will be formed at the conjugate focus (A′) behind the

Digitized by Illinois College of Optometry Library

retina, and the large diffusion circles at the level of the retina will only allow a blurred image to be seen. If it were possible to increase the converging power of the eye so that the focus were brought nearer so as to lie upon the retina (from A′ to R), it would be still possible to retain a distinct image ; this power of changing the focus is called *accommodation.*

There are four obvious ways in which accommodation could be brought about. In the first place the eye could be made to elongate so that the retina was moved out to A′ ; this is the method adopted to alter the focus of a camera where the photographic plate is moved, and a somewhat similar arrangement is seen in the eye of the mollusc *pecten*. Thomas Young, however, showed that it did not occur in man. Having particularly prominent eyes, he found that by rotating his eye strongly inwards, he could affix two clamped iron rings, one in front of the cornea and the other immediately behind the macula ; then on strong accommodation he found that the phosphene caused by the pressure of the posterior ring did not alter, and so concluded that his eye did not elongate.

In the second place, an increase of converging power might be attained by increasing the curvature of the cornea ; this, indeed, is the mechanism seen in some birds. Again the ingenuity of Thomas Young disposed of this possibility in the case of man. He immersed his eye in water, thus eliminating the effect of the cornea, replaced the corneal refraction by a suitable convex lens, and then found that his power of accommodation was unaffected.

A third method by which this end could be attained would be by altering the position of the lens and making it advance forwards. This occurs in fish, but in the human eye Tscherning showed that an advance of about 10 mm. would be necessary to give the full range which occurs normally, and this, of course, is out of the bounds of possibility, since the depth of the anterior chamber is only 2·6 mm. This leaves us with a fourth alternative —the modern theory—which attributes the mechanism of accommodation to an increase in the refractivity of the lens.

The Mechanism of Accommodation.—There is still a considerable amount of controversy as to the precise nature of the mechanism of accommodation. Every one is agreed that the essential feature is an increase of the curvature of the lens which affects mainly the anterior surface. It can be shown quite definitely that in the state of rest the radius

Digitized by Illinois College of Optometry Library

of the curvature of this surface is 10 mm., while during accommodation it decreases to 6 mm.; this alteration in shape increases the converging power of the eye so that the focus can be altered as is required. Helmholtz considered that the lens was elastic, and that in the normal state it was kept stretched and flattened by the tension of the suspensory ligament. In the act of accommodation the contraction of the ciliary muscle lessened the circle formed by the ciliary processes, and thus relaxed the suspensory ligament; relieved of the strain to which it had been subjected, the lens then assumed a more spherical form. Tscherning,

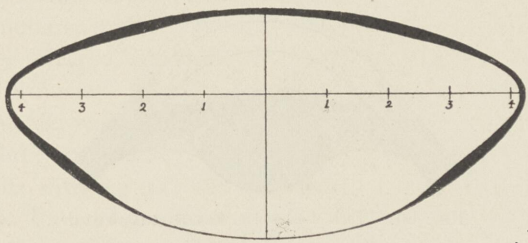


FIG. 85.—THE LENS CAPSULE.

Constructed from post-mortem appearances. The relative thickness is magnified 100 times. (Fincham.)

however, contested (and rightly) that in the act of accommodation the anterior surface of the lens assumed, not a spherical, but a hyperbolic form; and in order to account for the formation of this anterior lenticonus, he suggested that the contraction of the ciliary muscle tightened the suspensory ligament and compressed the lens against the vitreous, an action which caused its anterior surface to bulge forward. Neither of the two theories as they stand can explain all the phenomena of accommodation, and the work of Hess, Gullstrand, and, within the last year or two, of Fincham, Hartridge, and others, points to the probability that although the essential mechanism is based upon the principles suggested by Helmholtz, their application is modified by other

Digitized by Illinois College of Optometry Library

factors which allow for the peculiar deformation of the lens observed by Tscherning.

The lens is a completely inelastic structure, but, during the period of life at which accommodation is active, it is soft and endowed with a considerable degree of plasticity so that it can be moulded. It is enclosed within a capsule, which is extremely elastic, by means of which it is anchored by the suspensory ligament to the ciliary processes; the capsule varies in thickness, being thickest at the periphery and thinnest at the poles. Fincham's conception of it, as reconstructed from post-mortem examinations, is seen in

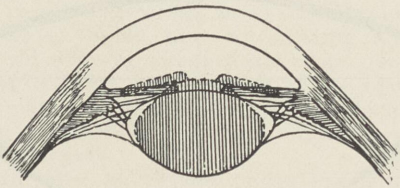


Fig. 86.—The Lens in Accommodation.

A diagrammatic representation of the change in shape of the lens in the act of accommodation. The unshaded lens with the line outline represents the normal condition; the shaded lens with the dotted outline represents the accommodated condition. The conus on the anterior surface is to be noted.

Fig. 85. In the normal state the capsule and the suspensory ligament are taut. During the act of accommodation the suspensory ligament is relaxed, and the capsule becomes considerably slacker—so slack is the suspensory ligament in maximal accommodation that, when the lens is *in situ*, it can be made to tremble (Hess), and when it has been absorbed after trauma, the capsule can be seen to float about in undulating folds (Graves). Relieved of the strain, the capsule, which hitherto had compressed the lens, bulges out preferentially at its thinnest parts—the two poles. Movement at the posterior pole is limited by the presence of the vitreous, which is probably pushed forward to a slight degree by the posterior attachments of the ciliary muscle pulling on the

Digitized by Illinois College of Optometry Library

choroid, and consequently the greatest change is seen at the anterior pole, which tends to assume a hyperbolic form (Fig. 86). During the act of accommodation, therefore, owing to the relaxation of tension of the elastic capsule, the lens increases in thickness and decreases in diameter, showing at the same time a protrusion forwards at the centre and a relative flattening at the periphery.

Physical and Physiological Accommodation.—It is obvious that two factors enter into the efficiency of the act of accommodation : the compressibility of the lens, and the power of the ciliary muscle. If the lens substance becomes sclerosed and hard, as it does with advancing age, so that it is no longer plastic enough to allow of its deformation, accommodation cannot be effected, no matter how great the contraction of the ciliary muscle. On the other hand, a weak or paralysed ciliary muscle will not be able to induce changes even in a lens of fluid consistency. There are thus two distinct considerations entering into the mechanism of accommodation, and these Fuchs has differentiated as *physical* and *physiological accommodation*. Physical accommodation is an expression of the actual physical deformation of the lens, and it is measured in dioptres. Thus if the converging power of the eye is increased by 1 D, we speak of the expenditure of 1 D of accommodation. The physiological component has as a unit the *myodioptre*, which is taken as the contractile power of the ciliary muscle required to raise the refractive power of the lens by 1 D.

These two elements are fundamentally distinct, and although they normally correspond during the first half of life, they may become dissociated, and when they do so, they entail different pathological effects. Physical accommodation fails in later life when the lens loses its plasticity and becomes hard in the condition known as presbyopia ; accommodation is therefore impossible, while at the same time the available ciliary power may be unimpaired. Conversely, a failure of the physiological power of the muscle may come

Digitized by Illinois College of Optometry Library

on in states of debility at any age, diminishing or abolishing accommodation, although the lens is eminently deformable. Since an attempt is made to overcome the muscular deficiency by a sustained and exaggerated ciliary effort, such a weakness may be responsible for distressing symptoms of asthenopia and eye-strain.

Like all other muscles, the ciliary muscle is unable to work adequately over long periods when strained to the utmost of its power without showing signs of exhaustion and distress. Thus, provided the work is not placed closer to the eye than the near point, it is possible to see, but if long-continued work is to be done, it is necessary that some power be held in reserve if it is to be done at all comfortably. Landolt estimated that in such circumstances two-thirds of the accommodation could be made available, and that about one-third of the total accommodative power must be held in reserve. This latter fraction is therefore designated *reserve accommodation*.

The Range and Amplitude of Accommodation.—The furthest distance away at which an object can be seen clearly is called the *far point* (*punctum remotum*). In order to see such an object the emmetropic eye is in a state of rest, the ciliary muscle is relaxed, and the refractivity is at a minimum. We have seen that by an effort of accommodation objects nearer than this can be seen distinctly; when the ciliary muscle has contracted as much as it can, the lens has assumed its greatest convexity, and the maximum accommodation is in force, the nearest point which the eye can now see clearly is called the *near point* (*punctum proximum*). At this point the refractivity of the eye is at a maximum. The distance between the far point and the near point, that is, the distance over which accommodation is effective, is called the *range of accommodation*. The difference between the refractivity of the eye in the two conditions—when at rest with a minimal refraction, and when fully accommodated with a maximal refraction—is called the *amplitude of accommodation.*

Digitized by Illinois College of Optometry Library

In the first case, where no effort is involved, we call the refraction *static;* when the refraction is altered by the exercise of accommodation, it is spoken of as *dynamic*.

The distance of the far point in metres is traditionally referred to as r, and R denotes the refractive power of the eye when accommodated for r; p refers to the distance of the near point in centimetres, and P to the refractive power of the eye in accommodation for p; a refers to the range of accommodation, and A to the amplitude. It follows that $a = p - r$ and $A = P - R$.

The accommodation is usually measured in dioptres, but since 1 dioptre represents a focal distance of 1 metre, the two are easily interchangeable, the refractive power, as we have seen (p. 47), being the reciprocal of the focal distance in metres. Thus if r is 1 metre, R is 1/1 D, *i.e.*, 1 D. If p is 10 cm., then P is 100/10, or 10 D. Thus, in order to focus an object at 10 cm. (10/100 metre), we require ten times as much accommodation as is required to focus it at 1 metre.

The Measurement of the Accommodation.—Although theoretically at infinity, the far point is taken in practice at 6 metres, for at this distance the light from an object may be considered to enter the eye in approximately parallel rays. If vision is normal at this distance as measured by the test types (see p. 255), the range of accommodation (r) is therefore infinite, and the amount of accommodation thus employed (where $R = 1/\infty) = 0$. If vision is less than normal at 6 metres, but, for example in a myope, is normal at 2 metres, then $r = 2$ and $R = 1/2$ or 0·5 D.

The near point is found by finding out the smallest distance at which the patient can see clearly. Usually a card containing fine print is taken as a test, and the patient is asked to approximate it towards his eye until the letters appear blurred.

Many other modifications of this test have been suggested. A wire optometer can be employed; this is a crossed wire stretched on a steel frame supported by a handle to which a measuring tape is attached. This may be graduated in centimetres or in dioptres (Prince's rule). The tape is held against the temple, and the instrument is gradually moved away until the wire cross becomes clearly defined, at which point the distance is read off on the tape.

Digitized by Illinois College of Optometry Library

A further suggestion is that of Scheiner. A card pierced with two small pin-holes situated close together is placed in front of the eye and the patient looks through the holes at a pin held about a metre away. At this distance the pin is easily seen as a distinct image, since the eye brings the two sets of rays coming through the two pin-holes to a single focus on the retina. If the pin is gradually brought nearer to the eye, however, a point will

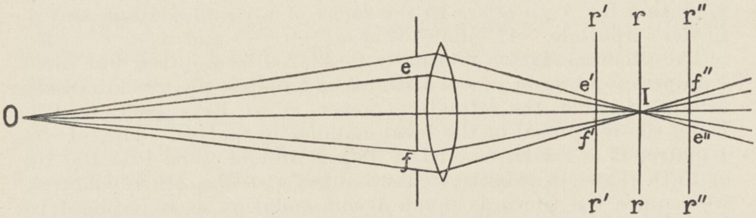


FIG. 87.—SCHEINER'S EXPERIMENT.

Let O be an object, and the two pin-holes, and *r* the retina. If *r* is not at the focus of the refractive system (represented here by a single lens) two images of the object O are seen, *e′f′* at *r′* or *e″f″* at *r″*. When O is thus brought nearer to the eye than the distance at which it can be brought to a focus on the retina, it appears double.

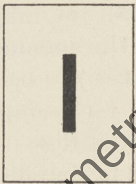


FIG. 88.—THE ACCOMMODATION CARD OF DUANE.

The line is 0·2 mm. thick and 3 mm. long.

be reached at which it will be unable to do this, and the pin will appear double (see Fig. 87); the point at which the image ceases to be single is the near point. Duane preferred to use a single thick line, 0·2 mm. thick and 3 mm. long, engraved on a card; when this is brought within the near point it blurs slightly and then appears double (Fig. 88).

Accommodation in the Emmetrope.—In an emmetrope distant vision is normal, and therefore *r* is at infinity and $R = 1/\infty = 0$. For distant vision, therefore, the eye is at

Digitized by Illinois College of Optometry Library

rest. If the near point is 10 cm. away (Fig. 89), $p = 10$ and $P = 100/10$ or 10 D. This latter figure gives the amplitude of his accommodation (10 — 0), and the range of the accommodation is infinite (∞ — 10).

The increase of refractivity called into play can best be

FIGS. 89, 90 AND 91.—ACCOMMODATION.

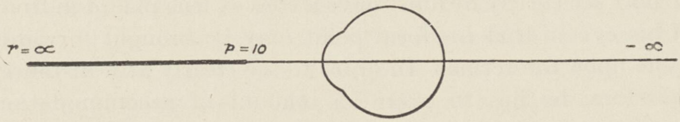


FIG. 89.—Accommodation in the emmetrope. $r = \infty$; $p = 10$. The amplitude of accommodation (10—0) is therefore 10 D, and the range is infinite.

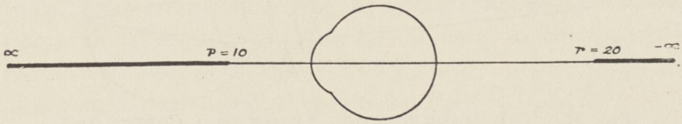


FIG. 90.—Accommodation in the hypermetrope of + 5 D. $r = -\frac{1}{5}$ metre, the far point being behind the eye; $p = 10$. The amplitude of accommodation is therefore 15 D [10 — (— 5)], and the range is again infinite.

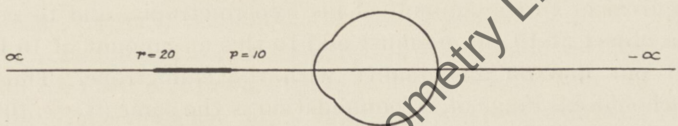


FIG. 91.—Accommodation in the myope of — 5 D. $r = 20$, $p = 10$. The amplitude of accommodation is therefore 5 D (10 — 5) and the range 10 cm.

understood by imagining the same effect produced artificially by a lens placed in front of the eye (Fig. 92). If the accommodation is paralysed so that only parallel rays are focused and distant objects are clearly seen, we shall find it necessary to place a + 10 D lens in front of the eye in order to see the object P, 10 cm. away. In this case the divergent rays from P are rendered parallel by the lens at p, and thus

Digitized by Illinois College of Optometry Library

can be brought to a focus on the retina of the non-accommodating eye. Thus the lens does the same work as the natural accommodation, and can be taken as a measure of it.

Accommodation in the Hypermetrope.—The hypermetrope on the other hand, sees nothing at all clearly at a distance without exercising his accommodation, since, as we have seen, his far point is situated behind the eye. In order that he may see clearly he must have a convex lens placed in front of his eye so that his focal point may be brought forwards to lie upon the retina. In order to see clearly at a distance, therefore, he has to exert an amount of accommodation

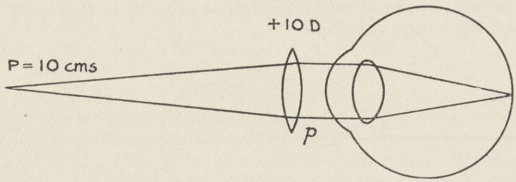


Fig. 92.—The Accommodation Effect of a Convex Lens.

With a convex lens (P) of + 10 D before the eye, rays coming from a point P, 10 cm. away, will be rendered parallel. They will therefore be focused upon the retina. In this way the lens does the work of accommodation.

equivalent to the amount of his hypermetropia, and to see an object at 10 cm. he must add to this an amount of 10 D to put him on an equality with the emmetrope. Thus, although his range of accommodation is the same ($\infty - 10$), the amplitude is necessarily greater.

This can be readily calculated from the same formulæ, always remembering that distances behind the eye are negative. If he has a hypermetropia of 5 D, so that his far point is 1/5 metre behind the eye (Fig. 90), and if his near point is 10 cm. away, the amplitude of accommodation is represented by $P - R$, *i.e.*, $100/10 - (-5)$, or $10 + 5$, *i.e.*, 15 dioptres. If we were to replace his accommodation by glasses, we would need to place a + 5 D lens before his eye when he was looking at distant objects, and when he

Digitized by Illinois College of Optometry Library

wished to see an object distinctly at 10 cm., a lens of + 15 D would be required. While, therefore, a hypermetrope has the advantage that he can compensate for his refractive error by accommodative effort, this faculty brings with it the disadvantage that if he is to see distinctly he must be making continual use of it, and when he does near work, the demands made upon the ciliary muscle must be still greater.

Accommodation in the Myope.—A myope brings parallel rays of light to a focus in front of his retina, and therefore has a far point at a finite distance in front of his eye. Suppose he can only see objects distinctly at a distance of 20 cm. away from his eye, his refractive error will be corrected by a lens of this focal distance (1/5 metre), and thus he will have a myopia of − 5 D. Let us imagine that his near point is also 10 cm. away from his eye (Fig. 91). His range of accommodation is therefore 20 − 10 cm., *i.e.*, 10 cm. At this point the refractive power of his eye will be + 10 D, and the amplitude of accommodation will therefore be P − R, *i.e.*, 10 − 5, or 5 dioptres. A myope, then, although he cannot see distant objects clearly by any effort of accommodation, has the advantage that he can see near work with considerably less effort than the emmetrope or the hypermetrope, being, in a sense, partially accommodated in his normal state.

Accommodation in Astigmatism.—In astigmatism, the eye, as we have seen, endeavours to focus one or other of the focal lines upon the retina, and uses its accommodation to do so whenever it is possible. As a rule an attempt is made to focus the more emmetropic line, failing which, or if the two are close together, the more vertical line. There is no evidence of the accommodative effort acting unequally in order to counteract the astigmatic error, and so it follows that a distinct image is never obtained. This, as we have already noted, leads to considerable discomfort on occasion, for the perpetually blurred image acts as a continual stimulation to further ciliary effort, which may well lead to much asthenopia and eye-strain.

Digitized by Illinois College of Optometry Library

Accommodation in Anisometropia.—If the accommodative effort of the two eyes could be dissociated, it would be possible for the error of an anisometrope to be corrected, within limits, by his accommodation ; thus if one eye were hypermetropic and the other emmetropic, and if the former alone accommodated, the two could be made equal. It has been proved, however, that this does not occur, and that the accommodation in both eyes is normally always equal and is never dissociated in this way. When correcting glasses are not worn, the image of one eye is therefore always blurred, and vision tends to be uniocular in proportion to the amount of refractive difference between the two. Especially where the error is small, however, the slight difference acts as an incentive for its correction, and since the end is never achieved, and the stimulus is always there, just as we have seen to occur in astigmatism, a considerable amount of accommodative strain may result (see p. 127).

The Availability of Accommodation.—It is seen from the examples illustrated in Figs. 89, 90, 91, that the range of accommodation is not by any means proportional to the amplitude. In the first place, an infinitely large alteration from infinity to 6 metres can be accomplished practically without effort, and the nearer we get to the eye a progressively shorter distance will require an ever-increasing power to cover it. Again, a hypermetrope will require to employ a greater amount of accommodation to see distinctly at a distance of 10 cm. than an emmetrope, and a myope may be able to see at this distance without effort. The range cannot therefore be taken to express the work done in accommodation ; this can only be appreciated by a consideration of the amplitude. On the other hand, the range is an indication of the *availability of accommodation* in that it gives us an idea of the distance at which clear vision is possible. Thus an emmetrope, or a low hypermetrope with active accommodation, is able to see distinctly over all ranges which may be considered to exist in practical life ; a

Digitized by Illinois College of Optometry Library

high hypermetrope whose near point is some considerable distance away may be incapacitated from all near work without the artificial aid of glasses; while a myope may have his far point so close to his eye that without glasses his vision is extremely limited, and his range so small as to render his accommodation practically useless.

Phenomena Associated with Accommodation.—There are two phenomena which are associated with accommodation, in that, although not necessarily accompanying it on all occasions or to the same degree, they usually act in concert with it. Such an associated action has been called a synkinesis (*σύν*, with; *κίνησις*, movement).

When looking at a distant object, the eyes are directed straight forwards, or approximately so, in order that the rays of light, which may be considered parallel, can fall upon both maculae; but if a near object is to be studied close up to the eyes, they must be turned inwards so that their visual axes are both directed upon it. The nearer the object the greater will need to be the convergence, and at the same time, the greater the accommodation.

Further, in looking at such a near object the pupil contracts. To some extent this action increases the acuity of vision by cutting off the outer parts of the lens and thus diminishing the optical aberrations associated with the periphery, but its most important function is to cut off the relative increase of light which enters the eye from near objects. Convergence is accomplished by the internal recti, and the pupillary contraction by the sphincter pupillæ, while the ciliary muscle governs accommodation; the close physiological association of these three synkinetic movements is seen in that all these muscles are supplied by the same nerve—the third cranial.

Digitized by Illinois College of Optometry Library

CHAPTER XII

CONVERGENCE

Hitherto, when considering the function of accommodation, we have assumed that vision is performed with one eye only, except merely to note that when the gaze is taken from a distant object and fixed upon a near one, the eyes must be converged. Originally, when the eyes were at rest and looking in the distance, the visual axes were parallel and no effort of accommodation was made; now, in order to see something clearly near at hand, not only must the eyes accommodate, but the visual axes must also be turned inwards so that they are both directed upon the object of attention. When this is done, the macula of each eye is brought into line with the object so that it can be seen distinctly; on the other hand, if convergence did not occur, the image would fall upon a different part of the retina in each eye and double vision would be the result.

If an object is gradually brought nearer to the eyes, they then converge more and more upon it, but ultimately a point is arrived at when the limit of convergence is reached. At this point the image appears double, and, giving up the sustained effort, the eyes usually diverge slightly outwards. Normally it should be possible to maintain convergence when the object is about 8 cm. away. This, the nearest point for which convergence is possible, is called the *near point* (*punctum proximum*) *of convergence.*

The near point of convergence is found by bringing a small object, such as a wire stretched vertically in a frame, or a luminous slit, or the accommodation card of Duane up to the eyes until it appears double. Care should be taken to distinguish the near point of accommodation from the near point of convergence; at

Digitized by Illinois College of Optometry Library

the former the test object appears blurred and indistinct, but is not necessarily double. Although the two points may coincide, this does not by any means always occur. Theoretically the distance should be measured from the line joining the centres of rotation of the two eyes (the *base line*), but in practice it is measured from the anterior principal focus, and an average correction of 25 mm. is added on to the measurement found.

The relative position of the eyes when they are completely at rest is called the *far point* (*punctum remotum*) *of convergence.* Ideally, this condition would be attained when the eyes are directed straight forwards with their visual axes parallel, in which case the far point would be at infinity. We have already seen, however, that as a rule the visual and the optic axes do not coincide (p. 68), but that in the position of rest there is generally (although not always) a slight deviation of the visual axes outwards. The far point, instead of being at infinity, is thus situated "beyond infinity," and, corresponding to the far point of accommodation in the hypermetropic eye, can be found mathematically by producing the axes backwards so as to meet at a point behind the eye. On the other hand, in those cases where there is an apparent convergence of the eyes in the position of rest, the far point will be situated at a finite distance. Corresponding to the terminology used in accommodation, the distance between the far point and the near point is called the *range of convergence*, and the difference in converging power required is called the *amplitude of convergence.* That part of the range of convergence between the eye and infinity is described as *positive*; that part "beyond infinity," that is, behind the eye, and which in reality is a divergence, is spoken of as *negative* convergence.

The Measurement of Convergence.—A convenient method for measuring convergence was proposed by Nagel, the unit of which is called the *metre angle* (m.a.). Let us imagine that when the eyes are at rest the visual axes are directed straight forwards in parallel lines (Fig. 93). Suppose now that they are converged upon an object situated 1 metre

Digitized by Illinois College of Optometry Library

away on the median line between the two eyes, then the angle which the line joining the object to the centre of rotation of either eye makes with the median line is called 1 metre angle. The angular displacement will necessarily vary with

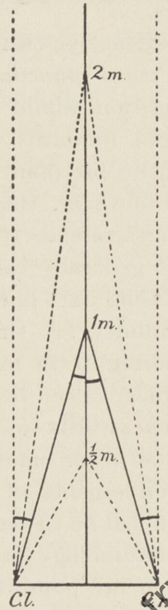


FIG. 93.—THE METRE ANGLE.

Cl and *Cr*, the centres of rotation of the two eyes. When the object is 1 metre away, the angle which *mCl* makes with the median line is 1 metre angle. Similarly at 0·5 metre, the corresponding angle is 2 metre angles, and at 2 metres, the corresponding angle is 0·5 metre angles.

the distance between the two eyes. With an interpupillary distance of 60 mm., this angle is about 2° (see Appendix III.). If the object is 2 metres away, the angle will be halved (0·5 m.a.); if it be brought nearer, say to 0·5 metre, the angle will be doubled (2 m.a.). The normal amplitude of convergence may be taken to be 10·5 metre angles, which is made up

Digitized by Illinois College of Optometry Library

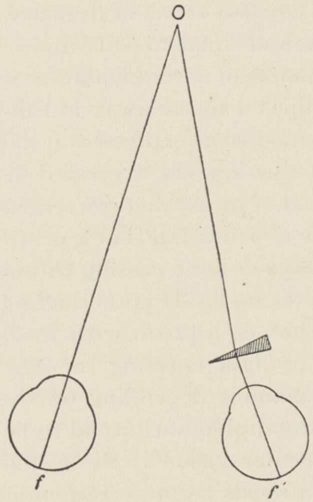


FIG. 94.—THE EFFECT OF AN ADDUCTING PRISM BEFORE THE EYE.

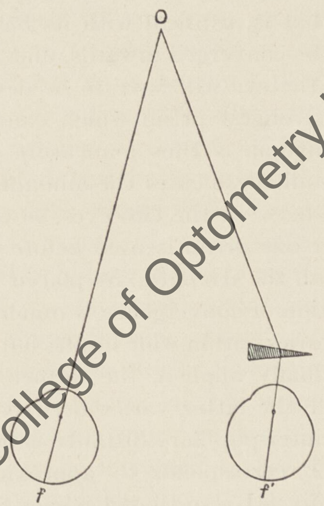


FIG. 95.—THE EFFECT OF AN ABDUCTING PRISM BEFORE THE EYE.

Digitized by Illinois College of Optometry Library

of 9·5 m.a. of positive and 1 m.a. of negative convergence, but it may exceed this and equal 15 or 17 m.a. It will be remembered that the amount of accommodation used by an emmetrope to see an object 1 metre away is 1 dioptre, so that the amount of accommodation expressed in dioptres is the same as the amount of convergence expressed in metre angles.

A second method of measuring convergence is by means of *prisms*. It will be remembered that a prism has the property of deviating the rays of light passing through it so that they are bent towards its base. If an adducting prism be placed before one eye (that is, a prism with its base directed outwards) the rays of light entering the eye will be deviated outwards by an amount depending on the strength of the prism (Fig. 94), and diplopia will tend to be produced. Consequently, if binocular vision is to be maintained, the eye must be turned inwards by a corresponding amount. The strongest adducting lens through which binocular vision can still be retained is therefore the measure of the power of convergence. Conversely, if an abducting prism be placed before the eye (that is, a prism with its base inwards), the rays of light will be converged inwards, and in order to compensate for this, the eye will have to be deviated outwards (Fig. 95). The strongest prism which can be borne without producing diplopia is thus a measure of the negative convergence. In all these cases the amount of convergence is shared equally between the two eyes, so that the effect is the same whether one prism is used before one eye, or two prisms, each of half the strength, are placed before each eye. The positive portion of convergence is much larger than the negative ; each varies within wide limits, but on the average, with prisms gradually applied, the former can amount to about 30° *d*, and the latter varies between 1·5 and 4° *d*. Again, when the inter-pupillary distance is 60 mm., an angle of deviation of 2° corresponds to approximately 1 metre angle (see Appendix III.), so that it is easy to transpose the prismatic angle found into the generally accepted notation.

Digitized by Illinois College of Optometry Library

The Relation between Accommodation and Convergence.—We have seen that the two synkinetic functions of accommodation and convergence are normally closely interrelated. The relation between them, however, is quite elastic, and either can be exercised separately. For example, if we look at an object with both eyes and then, while still looking at it, place weak concave or convex glasses in front of the eyes, we can overcome the effect of the glasses by an effort of accommodation and still see the object binocularly : in this case we are making an effort of accommodation without employing convergence. Conversely, if we repeat the experiment, this time placing prisms in front of the eyes, we can still see the object distinctly, thus demonstrating that convergence can be called upon without involving accommodation. When accommodation fails in age, convergence is retained, and when the ciliary muscle is paralysed by atropine, convergence is still possible. It is indeed fortunate that this is so, for a dissociation of the two is necessary in ametropia. Thus an emmetrope who wishes to look at an object 25 cm. away exercises 4 dioptres of accommodation and 4 metre angles of convergence ; but a hypermetrope of 2 D must employ 6 D of accommodation, and a myope of 2 D will require only two, while the amount of convergence remains the same. If the relation between the two were immutable, the result would be that the hypermetrope, for example, would either have to employ 4 D of accommodation or 6 m.a. of convergence : in the first case the object would be indistinct and blurred, and in the second binocular vision would be impossible and a squint would develop. The hypermetrope, therefore, has to use his accommodation in excess of his convergence, and the myope his convergence in excess of his accommodation. The amount of dissociation which is possible is not, however, unlimited ; it can be increased by practice, and it varies with different individuals and in the same individual at different times. The effort to dissociate the two may give

Digitized by Illinois College of Optometry Library

rise to no trouble, while, on the other hand, it may be the cause of considerable distress ; indeed, the necessary amount of dissociation may on occasion be impossible of

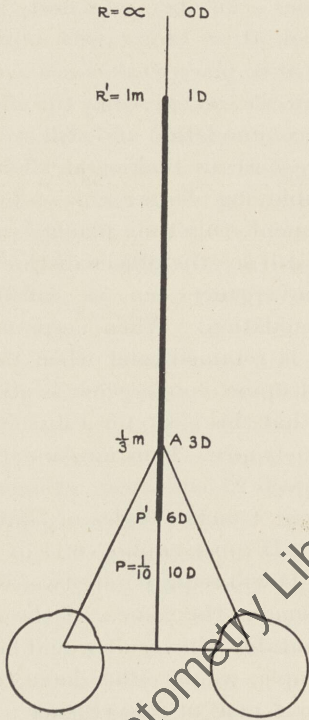


Fig. 96.—Relative Accommodation.

For convergence upon an object, A, $\frac{1}{3}$ metre away, the relative range of accommodation is R′P′ (*i.e.*, 100 — 17, or 83 cm.). The relative amplitude of accommodation is 6 D — 1 D, or 5 D. AP′ represents positive relative accommodation, R′A represents negative relative accommodation.

attainment, and since a clear image is of more immediate advantage than the retention of binocular vision, one eye may eventually deviate and a squint develop.

The amount of accommodation which it is thus possible to

Digitized by Illinois College of Optometry Library

exert while the convergence remains fixed is called the *relative accommodation;* the amount in excess of the convergence is called *positive,* that below, *negative.* The relation between these will be made clear from Fig. 96.

The subject is emmetropic, and has his far point (R) at infinity and his near point (P) at 10 cm. Suppose he looks at an object (A) situated 33 cm. away, he will then be exercising 3 D of accommodation and 3 m.a. of convergence. Concave glasses are now placed in front of his eyes until the object begins to be blurred; if this occurs with − 3 D glasses he has augmented his accommodation from 3 to 6 D, and his relative near point (P′) is at a distance equivalent to 6 D, that is, at 17 cm. Convex glasses are now substituted for the concave ones, and it is found that the image begins to be blurred when lenses of + 2 D are presented. He has thus relaxed his accommodation by 2 D, that is, from 3 to 1 D, and his relative far point (R′) is at a distance from the eye equivalent to 1 D, that is, 1 metre. For 3 m.a. of convergence, therefore, the relative far point is at 1 metre, the relative near point is at 17 cm., the relative range of accommodation is 83 cm. (R′P′), of which 67 cm. (R′A) is negative and 16 cm. (AP′) positive, and the relative amplitude is 5 D (*i.e.*, 6 D − 1 D), of which 2 D is negative and 3 D is positive.

It is obvious that the nearer the object is to the eye, the smaller will be the positive and the larger the negative range of accommodation. In the ultimate, if the eyes are emmetropic, when the object of fixation is at infinity, there will be no negative accommodation, and it will be found that no convex glass can be tolerated and at the same time good vision obtained. Similarly, if the object is at the near point, the positive moiety will have become *nil*, for here no concave glass can be tolerated since it requires all the accommodative effort possible to see an object at this distance. Thus, while there is one absolute far point, one absolute near point, and one absolute range of accommodation, there is a different relative far point, near point, and range for every degree of convergence.

In practice, it is only necessary to measure the amount of relative accommodation at 33 cm., that is, with a convergence of 3 m.a. The patient is first rendered emmetropic

Digitized by Illinois College of Optometry Library

with glasses, and small type is held at this distance from the eye. Concave lenses are then put up until the strongest is found which enables him to see readily; this is a measure of the amount by which he can augment his accommodation, *i.e.*, of the positive accommodation. A similar procedure is carried out with convex lenses; this is a measure of the

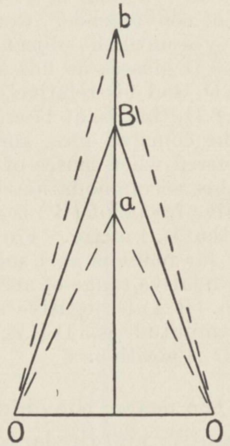


Fig. 97.—Relative Convergence.

O and O represent the centre of rotation of the two eyes. The eye looks at B, and keeps this amount of accommodation constant. Prisms, base out, are then placed before the eyes until the limit of single vision is reached: the deviation produced (*Ba*) is the positive portion of the relative convergence. Similarly prisms, base in, are used, and the negative portion (*Bb*) of the relative convergence for the accommodation required for B is found. The total relative convergence is *ab*.

amount by which he can relax his accommodation, *i.e.*, of the negative accommodation: and the sum of the two gives the total relative accommodation.

The importance of this relationship is that it is essential for comfort that the positive portion of the relative accommodation should be as large as possible; it should be at least as great as the negative portion. When it is large, the patient has a correspondingly large amount of accommodation in

Digitized by Illinois College of Optometry Library

reserve, but in the opposite case he will be working too near the limit of his capacity for comfort, for, like all other muscles, the ciliary muscle becomes fatigued if it is called upon to contract to its utmost for any length of time. If for any reason the amplitude of accommodation is diminished, and the near point recedes to the region of the working distance so that the positive accommodation becomes small, prolonged near work can only be undertaken without distress if convex glasses are provided which bring the range of accommodation nearer to the eye.

In a similar manner, if the accommodation be kept constant, the convergence may be made to vary. The amount of convergence which can thus be exerted or relaxed is called the *relative convergence*. This can be measured in a manner similar to that described for relative accommodation by accommodating for a fixed object and varying the convergence by prisms (Fig. 97). The strongest prism, base outwards, which can be tolerated without producing diplopia is a measure of the positive portion (*Ba*) of the relative convergence (*ab*), or the amount by which the normal convergence can be augmented. Similarly, the strongest prism, base inwards, which can be borne is a measure of the negative portion (*Bb*) of the relative convergence, and is the amount by which the convergence can be relaxed. Again, it is preferable for comfort that the positive portion should be the greater; and if it is not so, it may be advisable to prescribe prisms, bases in, to assist the convergence of those who are doing much continuous near work. Percival finds that it is the rule for patients to be able to exercise only the middle third of their relative convergence for any length of time without fatigue. This he calls the "area of comfort." If, in his near work, a patient has habitually to go outside of this limit, either in a positive or negative direction, he should be provided with prisms so that his work is kept within his area of comfort.

Binocular Accommodation.—Not only are convergence

Digitized by Illinois College of Optometry Library

and accommodation closely related, they also have a mutual effect the one upon the other. This is most readily seen in the fact that when both eyes are being used the power of accommodation is notably increased, the increase being due to the stimulus which the act of convergence gives to its related function. The excess of binocular over uniocular accommodation averages about one-half a dioptre, although individual variations are large, and it may be as high as 1·5 D. Duane gives the following figures :

Below 17	years,	excess	averages	0·6 D.
18 to 31	,,	,,	,,	0·5 D.
33 to 53	,,	,,	,,	0·4 D.
Above 53	,,	,,	,,	0·3 D.

It appears to be quite definitely established that this additional accommodative efficiency is due to the stimulation derived from convergence. It is not a result of the accompanying pupillary contraction, for it occurs independently of this. Neither is it due to an increase in visual acuity depending upon the fusion of the two images from both eyes, for the increase is as notable in patients in whom one eye is amblyopic, or who have a diverging squint which allows of an effort of convergence but does not permit of a fusion of the two images. The two functions are closely interwoven physiologically, and it appears that their maximum efficiency can only be attained if, by working with and supplementing each other, their synkinetic action is retained.

Digitized by Illinois College of Optometry Library

CHAPTER XIII

PRESBYOPIA

When discussing the mechanism of accommodation we saw that the increased refractivity of the eye was brought about by the elasticity of the capsule allowing the plastic lens to assume a more globular shape. As age advances, however, the lens becomes more hard and sclerosed and less easily moulded, and consequently the power of accommodation becomes progressively smaller. In early youth, for example, the lens has a semi-fluid consistency, while at the age of seventy or eighty it has become so firm that the greatest contraction of which the ciliary muscle is capable is unable to make it alter in shape to any noticeable extent; thus a child of ten may have an amplitude of accommodation of 14 dioptres, while an old man of eighty will have none. There is a considerable amount of evidence, also, which goes to show that in addition to these changes in the lens, a certain amount of weakening of the ciliary muscle occurs as age advances, especially in the later years of life. This, of course, also tends to make the accommodative power less; but its action is of secondary importance. Thus, although the process of deterioration is associated largely with the physical accommodation, the physiological component enters into the matter to some extent.

As the process goes on it becomes more and more difficult to see near objects distinctly; that is, the near point gradually recedes. This loss of accommodation is not to be considered as abnormal, and it proceeds gradually throughout the whole of life without any sudden alterations. At first no inconvenience is experienced, but eventually a time comes

Digitized by Illinois College of Optometry Library

when the near point has receded beyond the distance at which the individual is accustomed to read or to work, and then being unable to see clearly, he becomes seriously inconvenienced. When it has progressed to this stage, the condition is called *presbyopia* (πρέσβυς, old ; ὤψ, the eye).

The Variation of Accommodation with Age.—The varia-

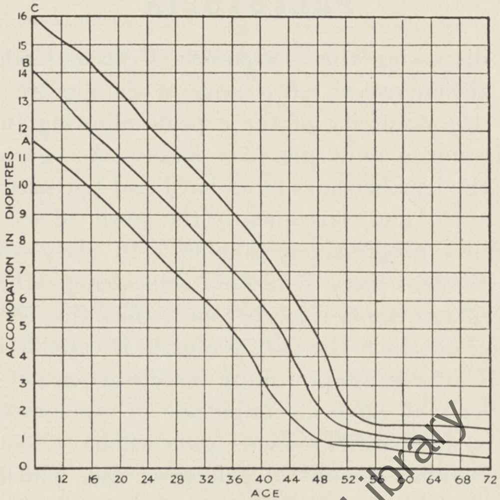


FIG. 98.—THE CHANGE OF ACCOMMODATION WITH AGE.

The amplitude of accommodation in dioptres is plotted against the age. The upper line represents the maximum accommodation, the lower line the minimum, and the middle line the mean. The figures are based on the observation of over 4,200 eyes, and represent the fullest accommodative power available in each individual. (Duane).

tion of the power of accommodation with age can be gathered from Fig. 98, which was compiled by Duane. He made a large number of individual observations, and the diagram is a representation of the average of the results.

It is seen that in the early years of life the amplitude of accommodation is about 14 D, and that the near point is situated at 7 cm. distance. Thereafter it gradually and uninterruptedly recedes ; at the age of thirty-six it has reached

Digitized by Illinois College of Optometry Library

14 cm., when the amplitude of accommodation has become halved, and is now 7 D instead of the original 14 D. At the age of forty-five it has reached 25 cm., and the amplitude of accommodation is only 4 D ; at the age of sixty only about 1 D of accommodation remains.

In the majority of cases near work is done at an average distance of 28 to 30 cm. away from the eyes, and therefore in the emmetrope the actual limit of clear vision is reached at forty-five years, when an amplitude of 3·5 to 4 dioptres of accommodation remains. This, however, would entail working at the near point continuously and thus exercising the whole of the accommodation to obtain useful vision, a condition of strain that cannot be tolerated over any length of time. Comfort demands that about one third of the accommodation be kept in reserve, so that when this limit has been reached, and the near point is at a distance of 22 cm., presbyopia may be said to have set in. In the emmetrope this occurs at about forty years. Thereafter the accommodation must be supplemented by a convex lens if near work is to be done without strain.

A hypermetrope starts life with his near point considerably further away than that of an emmetrope, and since the decline in accommodative power is approximately the same in both, the symptoms of presbyopia will come on earlier. Thus a hypermetrope with an error of + 3 D will require to exercise 7 D of accommodation to give himself an amplitude of 4 D ; he will therefore show presbyopic symptoms at about twenty-five years of age. In a myope, on the other hand, the opposite conditions hold, and if he has an error of — 4 D, presbyopia will never occur.

Presbyopia is thus a relative term, depending not only on the age but also on the refraction. It also varies with the individual and with his habits. A person with long arms, who holds his book far away, or who has got into the habit of reading with his book on his knees, complains of discomfort later than one who is used to reading more closely ; and the

Digitized by Illinois College of Optometry Library

carpenter or the book-keeper or the musician will be comfortable at his work at 30 or 35 cm. or over, while the seamstress or the compositor or the engraver of the same age, and with the same refractive error, will have been forced to use glasses in order to see at their working distance of 20 cm. Or again, the lens may become unusually sclerosed, an indication of general premature senility, or an expression of incipient cataract; or alternatively, the ciliary muscle may fail in states of debility or disease and the physiological accommodation be at fault. There is thus no fixed presbyopic point, and there can be no rational rule-of-thumb treatment.

Symptoms.—The failure of accommodation becomes evident gradually, and as a rule becomes apparent first in reading. Small print becomes indistinct, and in order to get within the limits of his receding near point, the patient tends to hold his head back and his book well forwards, until a distance is reached when clear vision under any circumstances is difficult. Trouble is experienced at first in the evening when the light is dim and the pupils are dilated, permitting of large diffusion circles; at this time, too, after the work of the day, fatigue comes on easily. The presbyope consequently likes to read by brilliant illumination, and he tries if possible to get the light between the book and his eyes so that his pupils may be forced to contract down and diminish the aperture. For this reason twilight is a difficult time, while in full daylight a person with a considerable degree of presbyopia may see small objects with remarkable distinctness in the open air, not so much because of the light itself, but because of the diminution of the size of his pupils. For this reason also, in more advanced years when the pupils become smaller in senility, an old person with no accommodation may see near objects with a fair degree of detail. Meantime, and this is important from the diagnostic point of view, vision for distant objects remains unimpaired. To this, of course, the hypermetrope is an exception, for when the power

Digitized by Illinois College of Optometry Library

of accommodation fails, the hypermetropia cannot be corrected and becomes entirely manifest, so that distant vision also becomes blurred and indistinct.

Complaint is usually made of visual failure rather than visual fatigue. The printed page becomes indistinct and letters and words are confounded. Sooner or later, however, symptoms of eye-strain appear. The ciliary muscle working near its limit becomes fatigued, and the accommodative effort, strained in excess of the convergence, gives rise to distress. Headaches are complained of, and the eyes feel tired and ache, and tend to assume the chronically suffused appearance so frequently seen in middle-aged adults.

Treatment.—The treatment of presbyopia is to provide the patient with convex glasses so that his accommodation is reinforced and his near point brought within a useful working distance. To do this adequately we must first know the working point of the individual, estimate his refraction, determine the amplitude of his accommodation, and then supplement this by the appropriate strength of lens allowing him a sufficient reserve accommodation.

Thus, if the patient is emmetropic and wishes to work at 25 cm., he will require an amplitude of accommodation of 4 D. Let us suppose that his near point has receded to 50 cm.: he has, in this case, 2 D of accommodation of his own. But he must, if he is to work comfortably, be able to keep one-third of this in reserve, so that he has an amplitude of 1·3 D, *i.e.*, $\frac{2}{3}$ of 2 D. The lens he requires theoretically is therefore one of 2·7 D. If he were ametropic, his refraction must be determined, and his near point estimated whilst wearing the correcting glasses which render him emmetropic.

It is frequently stated that in correcting a presbyope a correction of 1 dioptre for every five years above forty, until the age of sixty is reached, should be added to his refractive error; but in practice such a routine procedure will lead to a great deal of discomfort, and in the majority

Digitized by Illinois College of Optometry Library

of cases the glasses will not be tolerated. The correction of presbyopia should be made an individual thing. The amount of accommodation which remains at any age varies within wide limits in different individuals, a circumstance which depends among other things upon the state of physical senility. In each case the near point should be estimated separately for each eye, and the addition given should be based upon this and not upon the age. Occasionally it is found that the amplitude of accommodation is different in the two eyes, one having, for example, 1·5 D, and the other 2·5 D of accommodation left ; in such cases it is sometimes advisable to depart from the usual rule of adding the same correction to both eyes, and to give a correspondingly stronger reading glass to the eye with the weaker accommodation.

Again, it is unusual for reading to be done at 25 cm. A more usual distance is 30 cm., while writing and many other tasks allow a still greater distance ; for this a smaller addition is required. It is to be remembered that with a strong glass the far point is brought very near, the range of vision is correspondingly limited, and discomfort and annoyance are caused. Further, the association of convergence with accommodation calls for the provision of the weakest glasses that are compatible with good vision. There is a considerable amount of evidence that although the presbyope can only avail himself of a small amplitude of accommodation, the effort which his ciliary muscle expends is approximately the same as that employed by a young person with a larger amplitude. The lens of the former is much more resistant and difficult to deform under the influence of the elastic capsule, and the ciliary muscle may have to contract as much to produce an accommodative change of 3 D in a person of forty-five, or 1 D in a person of fifty-five as to alter the dioptric value by 14 D in a child of ten. While the physical accommodation, which is an expression of the actual optical result, is therefore widely different in these cases, the physiological component, which is a measure of the

Digitized by Illinois College of Optometry Library

effort expended by the ciliary muscle, may be approximately equal.

If too much of the available accommodation is replaced by glasses which are over-strong, this relationship is upset. This is probably the most usual cause of asthenopia and discomfort following the correction of presbyopia. If the glasses can be reduced in strength without involving a serious deterioration in visual acuity for work at the required range, they should be so reduced; but if this is impossible, and the maximum strength of glasses is required for any reason, the discomfort is usually completely relieved by adding to the lenses prescribed a prism with the base inwards, or alternatively, by decentring the lenses by a corresponding amount (see p. 353). Thus, while the sphere relieves the accommodation, the prism relieves the convergence.

On the average, provided the visual acuity is good, it will be found that for ordinary purposes the emmetrope of forty-five will require a correction of + 0·5 or + 0·75 D; at forty-eight he will require + 1 D; at fifty, + 1·5 D; at fifty-five, + 2·25 D; at sixty + 2·5 or + 3 D; and it is rarely necessary at any time of life to give a higher correction than + 3·5. To this the patient's refractive error must be added algebraically: if he is hypermetropic it is added, if he is myopic it is deducted from it. Thus, if he have an error of + 4 D, at sixty years of age he will probably require a reading glass of approximately + 6·5 D; if he be a myope of − 4 D, he will only require a correction of − 1·5 D for reading. An astigmatic error should, of course, also be added; sometimes it gives rise to discomfort, especially when glasses are now being worn for the first time. When this does occur, if the error is small, it may be omitted; but this should only be done with hesitancy.

Frequently the most useful type of glasses are bi-focals, a question which will be gone into in more detail later. The reading correction in such glasses should always be as small as possible. If a stronger correction is desired for reading at

Digitized by Illinois College of Optometry Library

night, for sewing or other fine work, it should be prescribed as a separate pair of glasses. Where convenience or necessity requires a less correction for vision at arms' length, as for playing cards, for music, or for work such as carpentry, a pair of glasses 1 or 1·5 D weaker should be prescribed to correspond with the near point which is desired.

On the other hand, where the visual acuity is poor, a stronger correction may be indicated so that the defect may be compensated by the formation of a larger image. This should be done only with caution. The smaller degrees of over-correction may give rise to no trouble, but should they do so, relief may be obtained by decentring or the addition of prisms. When a high over-correction is to be tried, it is usually advisable to confine the attention to the better eye alone, leaving the other uncorrected so that the disturbing effect of convergence is completely eliminated. When this is done it should be remembered that the uniocular accommodative power is less than the binocular; consequently it is necessary to add 0·5 D to the presbyopic glass which would normally be prescribed if the patient is to be placed in the same position as one with two eyes. Incidentally, such an additional correction is usually necessary in aphakia, when it frequently happens that one eye only is relied upon for vision.

Presbyopia is one of these conditions where a monocle, or a lorgnette, may be of real service: on the many little occasions in everyday life—when out shopping, looking at a ticket, or consulting a time-table—when the taking out of a pair of spectacles and the putting of them on for a moment become irksome, the more easily-manipulated monocle may save much time and not a little annoyance.

Digitized by Illinois College of Optometry Library

CHAPTER XIV

ANOMALIES OF ACCOMMODATION

It is certainly the case that in the estimation and correction of errors in the optical apparatus of the eye, the power of accommodation has not received the attention which it merits. It is the main defect in many cases of visual discomfort, and frequently the distress which may follow the wearing of glasses, especially at first, is due, not to inaccurate attempts at correcting the refractive error, but to an upset of the normal accommodation and its relation with convergence.

Accommodation has a fairly wide range which may be looked upon as normal (see Fig. 98), but variations in either direction, above or below that range, are by no means uncommon. These variations may be classified thus:—

(1) *Increase of Accommodation.* (*a*) *Excessive accommodation*, a relatively common condition wherein the accommodation is increased in the desire for distinct vision either under the influence of fixation or convergence, or under the stimulation of some exciting influence acting through the nervous reflex mechanism of the eye; this tends to cease as soon as the eyes are allowed to return to a condition of repose.

(*b*) *Spasm of the accommodation*, a rare condition, wherein a sustained contraction of the ciliary muscle occurs with inability to return by voluntary muscular relaxation to the normal muscle tone.

(2) *Diminution of Accommodation.* (*a*) *Insufficiency of accommodation*, in which the accommodative power is constantly sub-normal.

Digitized by Illinois College of Optometry Library

(*b*) *Ill-sustained accommodation*, in which the accommodation is initially normal in amount, but gives out after a short period of activity.

(*c*) *Paralysis of accommodation*, induced by disease or cycloplegics.

(3) *Inertia of accommodation*, in which difficulty is experienced in changing from one accommodative state to another.

(4) *Inequality of accommodation*, in which the accommodation in the two eyes is unequal.

(Presbyopia, the diminution of accommodation with age, is physiological.)

The Normal Range of Accommodation.—In order to appreciate the anomalies of accommodation, it is necessary first to appreciate the range within which the normal may be taken to lie. This has been most thoroughly done by Duane, who has based his results on the observation of over 4,200 eyes: his results have already been given in Fig. 98. Some of the figures upon which these are based are seen in the accompanying table. It is to be noted that the figures are based upon the fullest accommodative power obtainable in the individual,

AVERAGES OF MAXIMAL UNIOCULAR ACCOMMODATION FOR DIFFERENT AGES.

In dioptres measured at 14 *mm. from the cornea* (*Duane*).

Age.	Minimum.	Mean.	Maximum.
10	11·5	13·4	15·7
15	10·1	12·3	14·5
20	8·9	11·1	13·4
25	7·8	9·9	12·2
30	6·5	8·7	10·8
35	5·2	7·3	9·3
40	3·4	5·8	7·9
45	1·9	3·6	5·9
50	1	1·9	3·2
55	0·8	1·3	1·9
60	0·7	1·2	1·7

Digitized by Illinois College of Optometry Library

and they represent the minimum, the maximum, and the mean of these over the whole series.

It may be taken, therefore, with a fair degree of confidence, that if the amplitude of the accommodation of either eye falls without these limits, an abnormality exists ; and further, it is to be remembered that the binocular accommodation should be about 0·5 dioptre in excess of this, except after the age of fifty-three, when the amount which ought normally to be added should be smaller (about 0·2—0·3 D).

Excessive Accommodation.—We have seen that a certain degree of maintained accommodation is not infrequently found in young hypermetropes, but this is to be considered as a physiological adaptation in the interests of clear vision. A similar condition, however, is also found in myopes, especially in young subjects who are doing much near work, and it also on occasion accompanies astigmatic errors. It usually occurs in association with excessive convergence, and in many cases appears to be part of an attempt to obtain clarity of vision in spite of the presence of an optical anomaly. It is seen most frequently in young people, but it is not unknown in the middle of adult life, when presbyopia is beginning to become apparent, and the accommodation is being strained to an amount of work which it can only accomplish with difficulty.

A large amount of near work is an important factor in the ætiology of this condition, especially when the work is habitually undertaken in deficient or excessive illumination ; a refractive error is usually, but not invariably present, or alternatively, the wearing of improper or ill-fitting glasses may cause it ; and its occurrence may be associated with general debility and ill-health, sometimes with a local focus of irritation in the nose or teeth, and frequently with an unstable or neurotic nervous temperament.

The condition involves the production of an artificial myopia which varies from time to time, sometimes in the most bewildering fashion : a hypermetrope appears myopic, and a

Digitized by Illinois College of Optometry Library

myope more so. Both the far point and the near point are brought nearer to the eye, and distant vision becomes blurred. Vision is therefore improved by concave lenses, and these may perhaps be prescribed unwittingly, in which case, by thus catering to the spurious myopia, the condition becomes aggravated. In the more marked degrees near vision also suffers, and after reading for some time, the printed page becomes confused and clears up only after a temporary rest. Meantime, typical symptoms of accommodative asthenopia are usually present, with headaches and a feeling of fatigue and discomfort in the eyes themselves.

Even when undergoing an ophthalmological examination, the characteristic symptoms are observed. At one moment the visual acuity is good, at another bad; the objective examination of the refraction differs to a greater or less extent from the glasses chosen subjectively by the patient, and on verifying the former, a different refractive condition is once more suggested. A determination of the accommodation gives at one moment a small range at a high amplitude, and at another a range within the normal limits. Normally, after the exhibition of atropine and the abolition of the tone of the ciliary muscle, the refraction becomes hypermetropic by about 1 dioptre; the diagnosis of these cases of excessive accommodation is clinched by the discovery of a greater difference than this after the instillation of a cycloplegic. The dynamic refraction is quite incomparable with the static refraction.

The prognosis of such a condition is good, and the treatment usually effective. The refraction should be done under full cycloplegia; it is for this reason that atropine is essential for an adequate examination of the eyes of young people, for in them the lens is plastic and readily deformable and the ciliary muscle capable of great activity. The correction as found when the ciliary muscle is paralysed in this way should be ordered, deducting therefrom only such an amount as allows for the normal physiological tone of the

Digitized by Illinois College of Optometry Library

muscle, that is, about 1 dioptre. In the worst cases the eyes may well be kept mildly under the influence of atropine for a week or two in order to ensure absolute rest and allow the over-excited ciliary muscle to recover from its condition of strain and irritability. The general treatment is almost more important than the optical correction. Near work should be forbidden for a period, and thereafter its amount should be curtailed and the conditions under which it is undertaken supervised. The general condition of the patient's health should receive attention, for most of these subjects are ailing or over-worked or neurotic ; tonics and a holiday with a change of air usually have a greater beneficial effect than anything else.

Spasm of Accommodation.—True spasm of the ciliary muscle, a condition comparable to that brought about by miotics such as eserine, is rare, and very few authentic cases have been reported. The spasm is usually out of the control of the patient, and its amount may reach 10 dioptres or more, a high degree of myopia being produced. The patients are very frequently the subjects of a functional neurosis, and the element of hysteria may be considerable. With this is associated some irritating reflex influence, a marked degree of muscular imbalance, a trigeminal neuralgia, a dental lesion, or a general intoxication. Cases of irido-cyclitis have been reported, especially of the plastic type, wherein a temporary spastic condition of the ciliary muscle has been produced, presumably by the irritation of the inflammatory process ; in some cases a small degree of transient myopia has been observed.

The most effective method of treatment is the production of complete ciliary paralysis with atropine, and the cyclo-plegia must be kept up for a long time—four weeks or more. Even then the spasm not infrequently returns whenever the influence of the drug has passed off, when a further period of atropinisation must be prescribed. Correcting glasses should be worn immediately the eyes are used again, and

Digitized by Illinois College of Optometry Library

the general health and habits of the patient should be supervised as already indicated.

A well-developed condition of ciliary spasm is associated with the phenomenon of *macropsia* (μακρός, large; ὤψ, the eye). Here, objects appear larger than they really are as a result of a delusion of distance induced by the disturbance of the accommodation. An object close at hand appears larger than one a considerable distance away, and thus the size tends to convey an impression of distance. When the accommodation is in spasm, the amount of additional voluntary effort to see a near object distinctly is small, and, consequently, making little or no accommodative effort to see it, we judge it some considerable distance off, and, therefore, are led into the delusion that it is larger than it actually is.

Insufficiency of Accommodation.—In the condition of insufficiency of accommodation the accommodative power is constantly below the lower limit of what may be accepted as the normal variation for the patient's age (see p. 188). It is a relatively common condition, and may be due to one of two factors.

The failure may be *lenticular* in origin, arising from an undue sclerosis of the lens. It is thus in essence a premature presbyopia, and affects the physical accommodation only. It is a stable condition and gives rise to no symptoms except those of presbyopia, which sets in at an earlier age than the normal, the gradual recession of the near point appearing some years before the age and refractive condition of the patient would lead one to expect its occurrence.

On the other hand, the failure may be due to *weakness of the ciliary muscle*, and thus involves the physiological accommodation. Such a condition is usually labile, and varies within wide limits from time to time. Its ætiology embraces all the causes of muscle fatigue, and it is usually associated with general debility, anaemia, and mal-nutrition, accompanied by an excessive use of the eyes, especially for close work undertaken in unfavourable surroundings. The state of over-work is often associated with a neurotic tendency, and its effects are frequently intensified by such conditions

Digitized by Illinois College of Optometry Library

as general toxæmias due to intestinal disturbances, tuberculosis, and other chronic infections, and it may be intensified by local conditions in the nose, tonsils or teeth, by endocrine anomalies or arteriosclerosis. A rapid failure of accommodation also occurs in the prodromal stages of chronic glaucoma.

The symptoms may be productive of much discomfort. All the features of asthenopia and eye-strain may be present, with headaches, fatigue, and irritability of the eyes. Near work is blurred and becomes difficult or impossible, and the accommodative failure is frequently accompanied by a disturbance of convergence. Sometimes the attempt to accommodate brings on an excessive amount of convergence, but more often this associated function also fails, and there is a complicating deficiency of convergence. The duration of the condition is dependent upon the cause; with an improvement of the exciting factors, a betterment in the general health, or a relaxation from over-work or worry, the ocular condition may improve considerably, only to relapse at a later date if the same conditions again prevail.

When tests of the amplitude of the accommodation reveal the presence of such an accommodative insufficiency, and when it is giving rise to symptoms, treatment may be prescribed which usually brings a great deal of comfort. In the first place any refractive error should be corrected, and if vision for near work is seriously blurred and reading is therefore difficult, distance glasses correcting the refractive error should be supplemented by an additional pair of glasses for reading. The procedure to be adopted is the same as that described for presbyopia; the amplitude of accommodation is estimated and a lens of sufficient strength ordered, so as to bring the near point within reasonable distance. If there is an associated convergence excess, such glasses should be prescribed unhesitatingly, for by relieving the effort to accommodate, much of the stimulus to converge is removed. On the other hand, if there is convergence insufficiency, the addition of prisms, bases in, may add considerably to the

Digitized by Illinois College of Optometry Library

patient's comfort. The prismatic correction added should as a rule be such as brings the near point of convergence to the same distance as the near point of accommodation, and it generally corresponds to the spherical addition required. In all these cases only the weakest convex glass which will allow vision should be ordered, so that the accommodation may be exercised and stimulated rather than abrogated. For the same reason, as soon as recovery takes place, the additional correction for reading should be made progressively weaker from time to time.

Meantime, the accommodation may be considerably improved by the practice of exercises, provided the patient is intelligent enough to undertake them properly. The most simple of these involves the use of the accommodation test card (a black vertical line drawn on a white card is sufficient, as in Fig. 88), and he is instructed to practise with this at short periods throughout the day. The card is held a considerable distance away and then brought closer to the eye until the line appears blurred and indistinct; by repeating this he should be encouraged to attempt to bring his near point as close as possible, and to maintain his accommodative effort as long as he can with comfort. Such exercises will defeat their own ends unless they stop short of producing fatigue and distress, and if they are to be undertaken successfully, the patient should be one who can appreciate the physiological limits of his powers. The exercises should be undertaken only in those cases which are the result of ciliary under-activity, and in patients who are not in a state of general debility, in whom the condition of the ciliary muscles is not merely the local expression of generalised muscle weakness. In cases of lenticular sclerosis where the condition is stable and visual symptoms characteristic of presbyopia only are evident, such exercises are worse than useless in that they merely force the ciliary muscle to attempt the impossible. The exercises should be undertaken with the distance glasses on. Where there is an excess of convergence,

Digitized by Illinois College of Optometry Library

one eye only should be used at a time and the other should be covered; where convergence also is deficient, both eyes should be exercised simultaneously so that both functions are stimulated together, and in the later stages, the procedure already outlined can be combined with similar exercises with prisms, bases out, when the eyes are directed at a near object.

At the same time, treatment should be directed to the cause of the condition, if that be discoverable. Work, and the conditions of work, should be regulated, the general health should be improved in every way, and any suggestive toxic condition should be dealt with upon its merits.

Ill-sustained Accommodation.—Ill-sustained accommodation is essentially the same condition as insufficiency, but in a lesser degree. The range of accommodation is normal, but on any attempt to use the eyes for near work over a prolonged interval, the accommodative power weakens, the near point gradually recedes, and the near vision becomes blurred. Frequently it is the initial stage of a true insufficiency. The causes of the condition are the same as those just reviewed, it being common in convalescence from debilitating illnesses. The treatment is essentially the same, and is to be directed mainly to the reduction of work within the limits of the patient's capabilities and to general tonic measures.

Such a condition in a mild form is relatively common in those who read in the evening when they are tired, or in bed when they are physically relaxed. This, of course, is by no means surprising. The ciliary muscle shares in any general state of fatigue, and when the other muscles are tired and have demanded and have obtained relaxation, it would be strange if the ciliary muscle should be prepared to carry on uncomplainingly. In these circumstances, and in convalescence from illness, it is too often forgotten that reading or sewing entails muscular work in as true a sense as any other exercise, and these should be regulated on this understanding.

Digitized by Illinois College of Optometry Library

Inertia of Accommodation.—Accommodative inertia is a somewhat rare condition wherein the patient experiences some difficulty in altering the range of his accommodation. It takes some time and involves some effort for him to focus a near object after looking into the distance. It rarely assumes serious proportions, but on occasion may give rise to some trouble and annoyance. For its relief, any refractive error should be corrected, and accommodative exercises should be undertaken.

Unequal Accommodation.—An inequality of the accommodation is usually due to an unequal degree of sclerosis in the lenses of the two eyes occurring at the presbyopic age. No symptoms are produced until presbyopia is reached by the eye which retains its accommodative power longest, and then visual symptoms for near work are complained of. Glasses should then be ordered, and it will usually be found that these will prove more comfortable if the presbyopic addition is unequal, the eye with the lesser accommodation receiving a somewhat stronger addition than the other, in proportion to the deficiency found by actual tests.

An unequal accommodation also occurs pathologically in unilateral ophthalmoplegia and after traumatism, in which case it is usually associated with an inequality of the pupils, a dilatation occurring owing to an associated interference with the sphincter of the iris.

Paralysis of Accommodation.—Paralysis of accommodation may be artificially produced by drugs, such as atropine and homatropine, or it may be the result of disease.

In the latter case it is due to a paralysis of the ciliary muscle or the oculo-motor nerve, and may be associated with other paralytic lesions in the muscular apparatus of the eye. Usually it is accompanied by a paralytic dilatation of the pupil. Its origin may be nervous, toxic, or traumatic. It may occur in diseases of the central nervous system, as cerebral syphilis, tabes, and it is relatively common in encephalitis lethargica, in the diagnosis of which it may

Digitized by Illinois College of Optometry Library

provide information of considerable value. It has also been noted in herpes febrilis. It may be associated with any profound toxaemia, bacterial or otherwise. It has been described in influenza, in tonsillitis, in typhoid, in pneumonia, and it forms a well-known complication of diabetes. Diphtheria is a common cause, when there may be an accompanying paralysis of the palate; and since the paralysis comes on some weeks after the initial symptoms, it may not readily be associated with what may have perhaps been regarded only in the light of a "sore throat." Here again its occurrence is of diagnostic importance. It is found in chronic alcoholism, in food poisoning, ptomaine poisoning and botulism, and in poisoning from belladonna. In contusions of the eye-ball it is a purely local manifestation.

In paralysis of the accommodation the near point recedes and approximates to the far point, and objects close at hand appear blurred. Vision in the distance, however, is not necessarily impaired, although the enlarged pupil which usually accompanies the condition accentuates any optical defects the eye may already have. It also tends to produce an uncomfortable amount of dazzling. The phenomenon of *micropsia* is also evident; it is the reverse of the *macropsia* which occurs in accommodative spasm. Objects appear smaller than they really are owing to a delusion of distance induced by the accommodative anomaly. To see an object distinctly necessitates a great effort, and thus we take it to be nearer than it naturally is, and consequently, judged from this standpoint, we believe it to be unnaturally small.

It is seen that paralysis of the accommodation is a symptom of general disease, and with these the refractionist should be acquainted. The ocular lesion may form the most prominent symptom and the patient may come to him first for advice. A progressive paresis should suggest incipient glaucoma. A paralysis should suggest the presence of diabetes, or lead to an inquiry into a history of a sore throat that had received no attention, or to mild influenza or fever that may have been an

Digitized by Illinois College of Optometry Library

encephalitis. On the other hand, a belladonna plaster used for rheumatism, or contamination with an ointment containing atropine, very frequently explains away an occurrence which on first sight appears full of potential dangers.

The treatment of these conditions resolves itself primarily to a treatment of the cause. In paralysis of central nervous origin, as for example in cerebral syphilis or tabes, the prognosis is bad. In encephalitis lethargica the condition may be transient or may persist indefinitely into the post-encephalitic stage. In the toxic varieties the prognosis is favourable provided the toxaemia can be overcome; this includes diphtheria, diabetes, and the more direct poisons. In traumatic cases the condition may be permanent and the prognosis should be guarded. With regard to the local condition, especially in those toxic states where the lesion is not presumably permanent, no treatment is necessary. The eyes are better rested, no near work should be attempted, and general tonics, especially strychnine, should be relied upon. Stimulation of the ciliary muscle by eserine or by electrical methods has been suggested: the former probably does harm, and the latter rarely does any good. The proper treatment of the paralysed muscle is rest. When, however, recovery is delayed, and in those cases wherein the prognosis is bad, presbyopic glasses should be ordered which will allow the patient to read and work in comfort.

Cycloplegia

The Use of Cycloplegics.—A state of paralysis of the ciliary muscle is called *cycloplegia;* it may be produced by drugs instilled into the conjunctival sac, such as atropine, homatropine, and scopolamine, which are known as *cycloplegics.* These also paralyse the sphincter muscle of the iris, causing a dilatation of the pupil; for this reason they are also called *mydriatics.* All drugs which dilate the pupil also paralyse the accommodation in some degree; and similarly, all drugs

Digitized by Illinois College of Optometry Library

which constrict the pupil (*miotics*, such as eserine or pilocarpine) stimulate the ciliary muscle to contract, and induce some degree of spasm of the accommodation.

Both these properties of cycloplegia and mydriasis are of service in the estimation of refractive errors. By paralysing the ciliary muscle all accommodation can be abolished, and errors which before were latent are rendered manifest. The eye being thus put into a state of rest, its static refraction as opposed to its dynamic refraction can be estimated, and the disturbing influence of accommodation can be abolished. The dilatation of the pupil, moreover, makes the technique of estimating the error easier, especially in those whose pupils are abnormally small : it also assists in allowing a thorough and easy examination to be made of the interior of the eye. Lastly, in cases showing symptoms of strain and asthenopia, drugs which have a prolonged period of action, such as atropine, by forcing rest upon the eye, enable it to recover largely from its state of fatigue and keep it from further over-action until the correcting glasses are prepared.

The use of these drugs, however, is not without disadvantages. The eye with its accommodation paralysed is a pathological eye, and cannot be legitimately compared with the normal organ. The dilatation of the pupil alters considerably the optical properties of its refractive apparatus, and intensifies the physical errors due to aberration through the peripheral parts of the refractive media. Further, the periphery of the pupillary aperture frequently has a refraction quite different from the central part, which is alone employed in the normal circumstances of life. Moreover, when the ciliary muscle is paralysed, the lens capsule is in a considerable state of tension, but when the muscle once more becomes active, it allows a relaxation of the capsule, and the lens becomes more spherical and its anterior surface assumes a hyperbolic shape. This is at its maximum in states of spasm of the ciliary muscle, but is present in some degree under the influence of its normal physiological tone.

Digitized by Illinois College of Optometry Library

It is insisted by some that the refraction should be estimated under cycloplegics in all cases below forty or forty-five years of age, that is, in all cases where a considerable accommodative activity may be assumed to exist; and it is suggested that the smallest error, particularly the smallest astigmatic error, which is found under these conditions should be neutralised by correcting glasses, which should be forced upon the patient even although they do not improve his vision. The question of the wholesale correction of minute astigmatic errors has been dealt with elsewhere (p. 17), but apart from the advisability of this principle, it would seem undoubted that the practice is physiologically wrong. If 0·12 dioptre of astigmatism exists under cycloplegia and mydriasis, then, when the pupil has assumed its normal dimensions, and the action of the normal ciliary tone has altered the shape of the lens, it will almost certainly follow that the same 0·12 dioptre will exist no longer. The refraction we set out to correct is not the abnormal refraction of the eye in a pathological state, but the refraction which determines the images cast upon the retina of the patient in his every-day life. The procedure outlined above is based upon the theory that the ciliary muscle counteracts the corneal astigmatism by producing a neutralising dynamic astigmatism in the lens; and as we have seen (p. 120), this theory is without foundation in established physiological fact.

Apart from this, a cycloplegia frequently involves certain economic disadvantages. During the period of its activity near work is impossible, and this the patient may not be willing or able to put up with, unless he is assured that it is essential to his well-being. Further, the adequate administration of a cycloplegic involves a considerable amount of time, and after its use a second examination, when the eye has returned to its normal condition, is frequently necessary; while this may easily accommodate itself to the routine of a hospital clinic, it may present difficulties under the conditions of private practice.

Digitized by Illinois College of Optometry Library

On the other hand, the refraction is certainly more difficult to estimate through the undilated pupil, and it requires more care and experience on the part of the refractionist. It also necessitates the best optical conditions ; the room should be dark and the source of illumination good. The room should also be large enough for the patient to fix an object (such as a small red point of light) at least 6 metres away, so that he has every inducement to relax his accommodation ; a thorough relaxation of the accommodation is difficult or impossible in a small dark room. The patient should also be intelligent enough to assist materially in corroborating the surgeon's objective findings with his subjective observations, and the tests which are employed should be delicate enough to enable him to differentiate small variations. Provided these conditions are present, there is no doubt that where excessive accommodation can be eliminated, the ideal refraction is one conducted without cycloplegia.

Finally, it must always be remembered that in the routine use of mydriatics the danger of producing glaucoma in a predisposed eye is by no means negligible. Before these drugs are used the possibility of such a complication should always be excluded. The signs which should excite suspicion are a small eye with a shallow anterior chamber, a sluggishly-acting pupil and a premature tendency to presbyopia, a history of seeing halos and of obscurations of vision, and above all, a full tension and the picture of cupping of the optic disc. When these are present, no mydriatic of any kind is admissible. Where doubt is felt, the only mydriatic which should be employed is cocaine, and the patient should be kept under observation until the pupil is fully contracted by the subsequent instillation of eserine. This last is a precaution which should always be adopted in cases over forty years of age.

It thus appears that the use of cycloplegics has definite indications and contra-indications. In all young people the strongest drug (atropine) should be used in every case, for

Digitized by Illinois College of Optometry Library

in these the activity of the accommodation is so great that its effects cannot be assessed. This should apply without reservation to those below fifteen or sixteen years of age. Between fifteen and twenty years, atropine is still preferable, but if the economic conditions of the patient forbid its use, the weaker drug (homatropine) can be relied upon provided it is properly administered. Between twenty and twenty-five, homatropine should preferably be used, especially in hypermetropes. Beyond this age, provided the conditions enumerated above are present, a cycloplegic is in most cases unnecessary, if there are no symptoms indicating accommodative asthenopia, if the objective findings in estimating the refraction correspond with the subjective choice of lenses by the patient, and if the accommodation and convergence on measurement are found to be of normal range for the age of the patient. If any of these tests prove suspicious, homatropine should be instilled. Above the age of forty, except for the rare cases of excessive accommodation which occur at the commencement of presbyopia, a cycloplegic is unnecessary.

After the use of a cycloplegic a certain amount of hypermetropia has to be deducted to allow for the normal tone of the ciliary muscle. With atropine in an emmetrope or a hypermetrope, this amounts to 1 dioptre as a rule, with homatropine to about 0·75 ; in the case of a myope where the ciliary muscle is not so well developed, a deduction of 0·5 is usually sufficient. Thus a refraction showing + 1 D of hypermetropia under atropine would be emmetropic, and one which appeared emmetropic would have − 1 D of myopia. Where the error is large, the adjustment must be more elastic : the question has been more fully discussed in dealing with the separate refractive conditions (see p. 94 and p. 114). A post-cycloplegic test should be done, and in a case of hypermetropia which is uncomplicated by a pathological condition of the accommodation, the strongest glass which gives maximal visual acuity and can be worn with comfort

Digitized by Illinois College of Optometry Library

should be given ; in a case of myopia, the error should be fully corrected unless it is of very high degree, when comfort will frequently only be obtained with a considerably weaker glass. In the case of astigmatism, the whole of the error should be corrected. For astigmatic errors of any magnitude (that is 0·25 D, and over), both the objective and the subjective examination under mydriasis are susceptible of greater accuracy than when accommodation is active, and the cylinder and its axis should be maintained. The only exception is formed by a very large error when a somewhat smaller cylinder may be more comfortably worn as a rule. But where a minute astigmatic anomaly is found under cycloplegia, which cannot be detected and is not accepted when the eye is in its normal state, it would seem illogical to incorporate it in the glasses prescribed.

Atropine.—Atropine is the strongest cycloplegic known. When instilled into the conjunctival sac it is absorbed into the anterior chamber through the cornea, and not only paralyses the ciliary muscle and the sphincter of the iris, but abolishes their tone, thus producing full cycloplegia and mydriasis. It dilates the pupil in about fifteen minutes, and soon afterwards begins its action upon the accommodation. This action, however, is slow, and it is necessary to prescribe it for two or three days before the examination in order that the paralysis should be complete. In young people whose accommodation is powerful it should be given three times a day on three successive days. The action on accommodation lasts from seven to twelve days, and pupillary dilatation persists a day or two longer ; consequently the patient is precluded from near work for a considerable time. This makes its use in a glaucoma suspect dangerous, the more so since no drug will overcome its effects, except (as has been recently reported) histamine.

It is prescribed in a strength of 1·0 per cent., either in the form of drops or ointment. The drops are usually made up in watery solution and the sulphate is used (Guttæ atropinæ

Digitized by Illinois College of Optometry Library

sulphatis 1·0 per cent. in aqua dist.); in the ointment a 1 per cent. solution of the alkaloid is employed in yellow vaseline (Ung. atropinæ 1·0 per cent. in vas. flav.). The ointment is on the whole the most useful preparation; especially in children it is more easily rubbed into the eye, for they frequently object strenuously to drops. In addition, it is more slowly and continuously absorbed than drops, much of which flow down the lacrimal passages and may (although rarely) give rise to symptoms of atropine intoxication (dryness of the throat, diminution of all secretions, excitability, etc.). Care should be taken, however, that ointment is not administered for some hours previous to the examination, as the grease on the cornea will impair its transparency and alter the regularity of its refraction.

Homatropine.—Homatropine acts more quickly and is less powerful than atropine, and its effects pass off more quickly. Its action starts in from five to fifteen minutes, is at its maximum in about three-quarters of an hour, and has passed off to a large extent in twenty-four hours. There is some residual impairment of accommodation, however, which may persist for two or three days, and for this reason any post-cycloplegic test should be postponed for such an interval. Especially when there is much latent hypermetropia, a slight insufficiency of accommodation may persist for over a week. Its action is overcome by eserine, and after the administration of this drug in a drop of 1 per cent. solution, near work should be possible within an hour or two. Homatropine is usually employed along with cocaine, which reinforces and accelerates its action, largely by increasing the permeability of the cornea. Some surgeons, however, object to its use on the ground that it tends to injure the corneal epithelium. It may be given as a 1 or 2 per cent. solution of the hydrobromide alone, or with an equal strength of the hydrochloride of cocaine in watery solution; or alternatively, the alkaloids in both cases may be prescribed in 2 per cent. solution in castor oil (Homatropine c. cocaine in ol. ricini, 2

Digitized by Illinois College of Optometry Library

per cent.). If the watery solution is used, its administration should be repeated two or three times at intervals of ten minutes, and the accommodation will be found almost completely under its influence in an hour or an hour and a half. The oily solution, on the other hand, remains in the conjunctival sac and is continuously absorbed, and therefore one drop only is required. Here again, care should be taken not to dim the surface of the cornea with an excess of oil.

As the action of homatropine is variable with different individuals, the depth of the cycloplegia should be tested in each case before the refractive examination is begun. This is easily done by testing the amplitude of accommodation which remains; this should not exceed 1·0 D., *i.e.*, the line on the accommodation card should become blurred at a distance of 1 metre. After the refraction has been done, the state of the accommodation may again be verified: a — 3 D sphere is added to the full correction, when the far point should be at 33 cm., and the near point slightly over 25 but not under 28 cm. If this amount of cycloplegia does not remain, and if the administration of the homatropine has been carefully done, excessive accommodation should be suspected, and further instillations should be given or atropine should be used.

There are other mydriatics which are less widely employed. *Hyoscine* (or *scopolamine*) *hydrobromide* in 0·5 per cent. solution has an action similar to atropine; it is, however, more transitory, lasting only about five days. *Duboisine sulphate* (1 per cent.) is exactly comparable. Both of them, however, may excite marked constitutional symptoms—giddiness, drowsiness, and dryness of the throat. *Hyoscyamine sulphate* (1 per cent.) has a similar action, lasting from six to seven days; its action is thus intermediate between that of atropine and hyoscine. *Euphthalmine* and *cocaine* act as mydriatics, but have little effect on the accommodation.

Digitized by Illinois College of Optometry Library

SECTION IV

THE MUSCLE BALANCE

CHAPTER XV

ORTHOPHORIA

Ideally, when the eyes are at rest and are regarding a distant object situated straight in front of them, the visual axes are parallel. This is called the *primary position.* When they are so disposed, rays of light on entering fall upon corresponding points on the retina of each, so that the two images can be fused psychologically into one, and binocular vision is possible. If the direction of vision is changed so that the eyes occupy any other (*secondary*) position, they must move in complete co-ordination if this psychological blending of the two sets of visual impressions is to be retained. Not only must *conjugate movements* be accurately balanced in this way, but *disjunctive movements* such as convergence and divergence must be delicately graded, so that when the two eyes fix an object at any distance, they are orientated so that the macula of each comes into the direct line of vision. When we remember the free mobility of the eyes, and their complicated control by six pairs of muscles, it does not seem surprising that an adjustment as delicate as the ideal conditions demand is not invariably maintained. The controlling influence which maintains this balance is the desire for binocular vision, and the reflex mechanism governed by this fusion faculty can force the peripheral muscles to orientate the eyes in the desired direction even in spite of considerable difficulties.

Digitized by Illinois College of Optometry Library

The condition wherein the actions of the muscles are normally balanced so as to allow of fusion without effort is called *orthophoria*, while conditions of imbalance are known as *squint* or *strabismus*. Where this imbalance is overcome by the efforts of the fusion faculty, so that the proper alignment of the eyes is maintained under duress, the condition is known as *heterophoria* (*latent strabismus*). But where this is found to be impossible, either because the muscular imbalance is too great or the power of the fusion faculty too weak or because the vision in the two eyes is unequal, one of the eyes deviates out of its proper direction, and the condition of *heterotropia* (*apparent strabismus*) is produced. Each of these pathological conditions is of importance clinically: the first because the continued effort may involve considerable distress and eye-strain, the second because the inconvenience and confusion resulting from the reception of two images which cannot be blended leads to the suppression of one, and the continual suppression of the images by one eye may ultimately result in the development of amblyopia in that eye.

Binocular Vision.—There are three essentials necessary for the attainment of binocular vision. Firstly, there must be two healthy maculae in the two eyes subserved by an efficient focusing mechanism, so that two clear and approximately equally distinct images can be formed. The visual acuity at the macula must be higher than at any other region of the retina in order that a sufficiently strong reflex stimulus can be sent to the external muscles to orientate the eyes so that the image of the object of attention will be formed there. The second essential, therefore, is a normally functioning set of ocular muscles which are competent to bring about the fine adjustment which is necessary. The last essential is an efficiently working nervous mechanism, which can receive the two impressions and blend them psychologically into one.

Although in normal circumstances the two eyes work

Digitized by Illinois College of Optometry Library

in close association and are treated as one by the brain, the two retinal images are not identical. When looking at an object, the right eye sees more on the right and the left eye on the left. These two images are fused psychologically, and their slight diversity, together with other facts derived from experience, permits an appreciation of solidity and depth and assists in the judgment of distance. The slight amount of diplopia which should theoretically be produced in this way

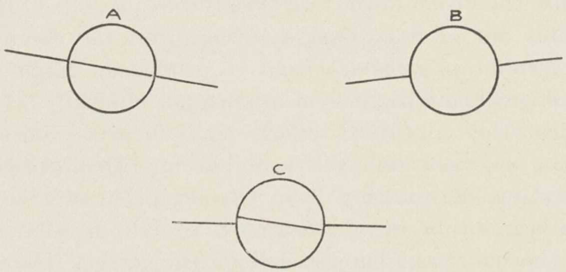


Fig. 99.—The Power of Fusion.

A is seen by the right eye ; B by the left. The lines outside the circle are fused into horizontal lines, as in C, while the line within the circle, which is seen by one eye only, remains oblique.

is suppressed, but at the same time both sets of impressions reach the brain, and their combination results in an appreciation of the third dimension in stereoscopic vision. We are thus enabled to project the mosaic of retinal images in their proper perspective in space, and to orientate ourselves in regard to them.

The optical adjustment, therefore, is not necessarily mathematically exact; indeed, the central co-ordination permits of a considerable amount of elasticity. When the two images differ by virtue of a failure in equilibrium between the two eyes, provided the disparity be not too great, the oculo-motor apparatus first places the eyes in their most favourable relative positions, and then the fusion faculty fills in the gaps psychologically.

Digitized by Illinois College of Optometry Library

This is seen in Fig. 99. If the two figures, A and B, be placed in an amblyoscope, it will be found that the oblique lines outside the circle will be fused into one horizontal line, while the line within the circle, which is seen by the right eye only, remains oblique.

The Fusion Faculty.—Some authors hypothecate a definite fusion sense localised in a distinct fusion centre in the brain ; and it has been suggested that squint is produced essentially by a failure in the development of this sense. This may or may not be ; but there is no adequate evidence for it. It is more probable that the fusion of the impressions from the two eyes depends upon the accuracy of the co-ordination of impulses derived from them by the cerebral mechanism as a whole. Squint may be due to failure of this co-ordination ; but on the other hand, it may as well be the cause of the deficiency, or the two may depend upon some other common cause.

However this may be, the faculty of binocular vision requires a complex system of inter-related reflexes in the brain which can only be laid down early in life. If a light is presented before a baby's eyes, he will merely fix it momentarily ; at two to three weeks of age he will maintain fixation for some seconds with one or other eye but will not converge accurately ; it is only at five to six months that he will fix it binocularly and maintain the fixation. Binocular vision is therefore not present at birth, but appears within the first six months of life ; and at about the age of six years the faculty of fusion is fully developed. It is only within these formative years that the reflex paths can be conditioned by training and educational exercises in cases where the normal development has been deficient. Up to the age of five or six such training is often successful and the results are satisfactory ; about the age of six the results are more in doubt ; but over six or seven years improvement is rare, and the results seldom justify the expenditure of time and trouble which methods of education require.

Digitized by Illinois College of Optometry Library

Binocular vision may be present in varying degrees. One person may be able to see objects clearly with each eye, and when the visual axes are in proper alignment the two images are superimposed so as to form one, but when any disturbing influence comes into play so that the axes are disorientated, there is no attempt to maintain fusion, and diplopia is produced. This has been called "simultaneous perception." A second person, however, will not only fuse the two images, but will make a considerable effort to maintain this fusion; while a third who not only sees binocularly but blends the

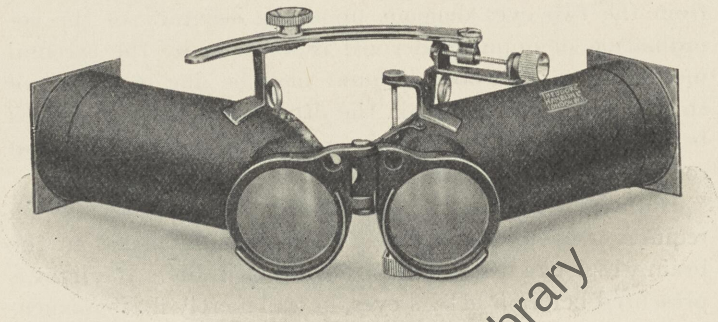


FIG. 100.—THE AMBLYOSCOPE.

two so as to obtain a stereoscopic effect, will have so great a tendency to maintain fusion that it is only with the greatest difficulty that he will abandon the advantages of binocular vision.

These grades may be detected most simply by the amblyoscope (Fig. 100). It consists of two adjustable tubes, each of which carries a picture which is presented to one eye.[1] If object-slides as represented in Fig. 101 be presented, and both eyes are able to see adequately, the cow and the moon are both seen. This represents simultaneous perception. If the instrument is adjusted for parallelism of the visual axes, and a composite picture is

[1] In the latest type of amblyoscope, in order to reflect the image round the bend of the tube there are totally reflecting prisms instead of mirrors, and each tube is provided with a small electric lamp, the relative bright-

Digitized by Illinois College of Optometry Library

presented so that each half of it is incomplete, as in Fig. 102, the parts missing in the image formed by the one eye are accurately superimposed by the other. When the fusion faculty is present the picture appears as one complete whole. Where there is no attempt to maintain fusion, as soon as the axes are

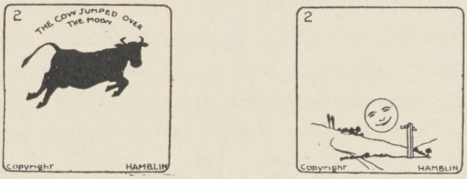


FIG. 101.—AMBLYOSCOPIC PICTURES.
To illustrate simultaneous perception.

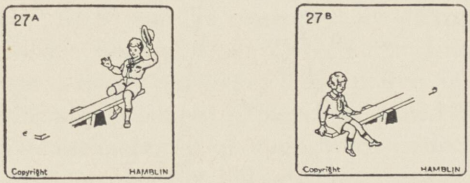


FIG. 102.—AMBLYOSCOPIC PICTURES.
To illustrate the capacity of fusion.

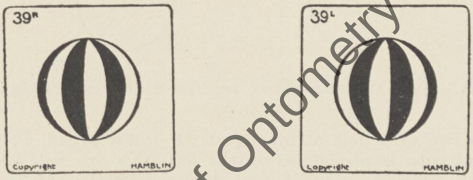


FIG. 103.—AMBLYOSCOPIC PICTURES.
To illustrate stereoscopic vision.

moved from the position of parallelism, the picture becomes broken up, and the extent to which the tubes may be separated

nesses of which can be varied. Alternatively, darkened glasses can be inserted into the tubes. Thus, by varying the illumination in those cases where the visual acuity is unequal in the two eyes, the weaker eye can be assisted and the stronger damped down, so that the impressions, being rendered more equal, are more readily fused psychologically.

Digitized by Illinois College of Optometry Library

or brought together, while still retaining the grouping of the figure intact, may be taken as a measure of the development of the fusion faculty. If the pictures shown in Fig. 103 be presented, a person with the second grade, with binocular but no true stereoscopic vision, will either suppress one of the figures or see the two unintelligibly mixed up ; but if true stereoscopic vision be present,

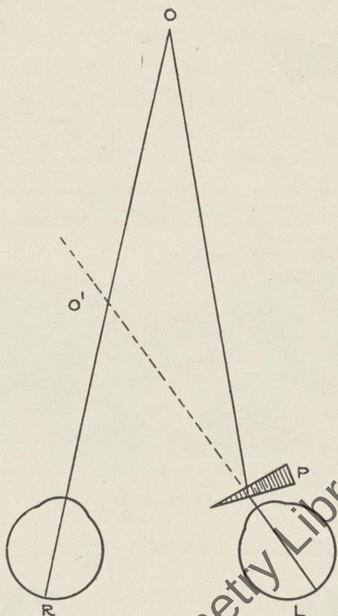


FIG. 104.—THE MEASUREMENT OF THE CAPACITY TO MAINTAIN FUSION.

If the two eyes look at an object, O, and a prism, P, with its base outwards, is placed before the left, this eye will be turned inwards so that the rays of light deviated by the prism still fall upon the macula. O therefore appears to the left eye to be displaced to O′, and double vision should be produced. This tendency to diplopia is overcome within limits by the power of fusion.

the two balls will be blended into one, giving a stereoscopic effect of almost "hitting one in the eye," an appearance so vivid that even young children will at once remark on it.

The amount of effort which can be put forth to maintain fusion can be measured by prisms.

Digitized by Illinois College of Optometry Library

If in Fig. 104 the two eyes are directed towards an object (O), and a prism (P) is interposed before one with its base directed outwards, the rays from O will be deflected outwards so that they strike the retina to the outer side of the fovea. In this case, since the rays still impinge upon the macula of the other eye, double vision would be produced. Consequently the first eye is turned inwards until the deflected rays fall upon the macula once more and binocular vision is again possible. In this case the ray sappear to come from O′, and to maintain fusion an excessive convergence is produced. The maximum effort which can be put out in this way is measured by the strongest prism with which diplopia is not produced. It is found that very large prisms, up to 30° or even 60°, can be overcome by *convergence*. Weaker ones from 5° to 8° can be overcome by *divergence*; and only still weaker ones of 1° or 2° by vertical deviation of the eyes (or *sursumvergence*). This power of suppressing an artificially produced diplopia is called the *verging power*, and its estimation is of importance in deciding upon the appropriate treatment indicated in cases where muscular imbalance exists.

Digitized by Illinois College of Optometry Library

CHAPTER XVI

HETEROPHORIA

We have seen that when the ocular muscles are not properly balanced so that the visual axes do not normally lie in alignment, the desire for binocular vision may act as a stimulus and force the eyes into a suitable position in order that the two images may be fused into one. This condition of imbalance, we have noted, is called heterophoria. It is caused by a relative insufficiency of one or other of the muscles. This implies that either the muscle itself is weak or that its antagonist is too strong, so that when the muscular apparatus is at rest and is subjected to the influence only of the normal postural tone, the eye will deviate in the direction of the relatively stronger muscle. It follows that in order to produce the parallelism which binocular vision demands, the weaker muscle will have to supplement its normal tone by a continuous active contraction, and will consequently never be at rest throughout the waking hours. The result of this constant activity is a liability to fatigue and eye-strain, which, depending upon the constitution and nervous condition of the individual, may protrude itself into consciousness and produce symptoms. Thus, although a squint is potentially present, it is masked by this active correction and remains latent. If, however, the muscular power required for correction is inadequate, as may occur in states of debility, or if the stimulus for fusion is not sufficiently strong, as may happen if the vision of one eye is much inferior, or if the neurological pathways subserving the co-ordination of the two sets of visual impressions have not been developed, an obvious deviation results: the latent

Digitized by Illinois College of Optometry Library

squint becomes manifest, the heterophoria becomes a heterotropia.

The Causes of Imbalance.—The state of normal muscular equipoise may be disturbed by several conditions. (*a*) The muscle may itself be weak, the deficiency being of congenital origin, or involving a lack of normal postural tone. Such a condition may be the result of illness or general weakness, anaemia or nervous debility, and corresponds to some extent to the similar condition which results in postural deformities, for example, as affecting the back, in scoliosis. At times when the vitality is good no trouble may be experienced, and the deviation may be evident only in states of bodily fatigue. The heterophoria may thus be rhythmic; it may tend to appear in the evening when the patient is tired, or it may cause distress during a period of over-work or anxiety and worry, and completely disappear when a rest or a holiday is secured. (*b*) Alternatively, spasm of the opposing muscle or an augmentation of its postural tone may be the cause of the condition. (*c*) Errors of refraction and disturbances of accommodation with the associated convergence may upset the muscle balance; thus trouble frequently commences when school or office work is started and an unaccustomed amount of near work becomes a necessity. (*d*) The anatomical arrangement of the muscles or the configuration of the orbits may be an ætiological factor. (*e*) Finally, disturbances of innervation may be responsible.

The Detection of Imbalance.—A very large number of methods are employed in order to detect disturbances in the equilibrium of the oculo-motor apparatus. The principle of all of them, however, is the same. We have seen that the eyes are forced into a strained position in order to fuse the images received by each. If this fusion is rendered impossible by making the two images entirely dissimilar, all desire for binocular vision will disappear, and the eyes will be free to return to their normal position of rest.

This may be done in a rough or ready way by covering up

Digitized by Illinois College of Optometry Library

one eye in the so-called *screen test*. The patient fixes an object—a point of light some distance away is best—and one eye is covered by a card: binocular vision is thus rendered impossible and the eyes take up a position of rest. Since the patient keeps looking steadily at the object with the uncovered eye, the position of rest is attained by a deviation of the covered eye. The card is then suddenly withdrawn, the stimulus of binocular vision at once reasserts itself, and the eye which was covered at once moves again into the position

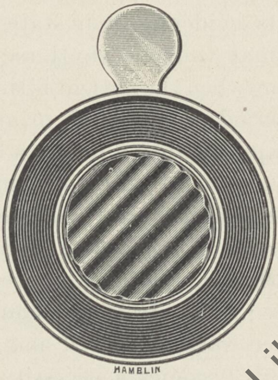


FIG. 105.—THE MADDOX ROD.

of strain wherein the visual axes are both directed upon the object of attention. It is this movement of the covered eye while the other remains stationary throughout which betrays the presence of heterophoria.

For the measurement of the amount of heterophoria, and for detecting its presence in slighter degrees, more delicate tests are necessary. Of these the most generally useful is the *Maddox rod test*. The Maddox rod (Fig. 105) consists of several red cylinders of glass placed sided by side in a frame, and when a spot of light is looked at through it, an image is formed as a focal line running perpendicular to their axes. The spot thus appears as a long red line running perpendi-

Digitized by Illinois College of Optometry Library

cular to the direction of the cylinders. It is evident that this red line will appear completely different from a white spot of light, and so when they are seen simultaneously by both eyes there is no stimulus for fusion. The Maddox rod is therefore held before one eye, and the patient asked to look at the spot of light, whereupon, the two images (the spot and the red line) being completely dissociated, the eyes immediately take up the position of rest. If there is orthophoria, the visual axes will remain parallel and the red line will run directly through the centre of the spot; if there is heterophoria, the visual axis will depart from the position of parallelism and the red line will be deviated away from the spot of light in one direction or another. At the same time the amount of deviation can be measured by the strength of prism which it is necessary to place in front of the eyes in order to get the two images to coincide.

It is to be noted that the rods must be accurately cylindrical; since if they taper at all, a deviation will be suggested which does not exist. Such a fault can be recognised by the fact that if the instrument is reversed, a similar deviation in the opposite direction will at once be evident. The clinical application of this test will be considered in the appropriate section (see p. 319).

Varieties of Heterophoria.—Depending on the muscle which is at fault, latent deviation may occur in several directions. These are classified thus:

Exophoria, the eyes tend to deviate outwards, there being a relative insufficiency of the internal recti.

Esophoria, the eyes tend to deviate inwards, there being a relative insufficiency of the external recti.

Hyperphoria, one eye tends to deviate upwards or downwards relatively to the other. A combination of deviations is sometimes spoken of as *Hyperexophoria* (up and out) and *Hyperesophoria* (up and in); while a condition of oblique disorientation, considered to be due to inadequacy of the obliques, is called *Cyclophoria*.

Digitized by Illinois College of Optometry Library

Exophoria.—Exophoria (Fig. 106), the condition wherein the visual axes tend to deviate outwards, is the most common anomaly of the muscle balance, for, as we have seen, the position of rest is most usually one of slight divergence. Where the divergence is actually in excess, the defect is greater for distant vision than for near vision. On the other hand it may be due to an insufficiency of convergence, in which case it is frequently associated with an insufficiency of accommodation. It thus occurs most

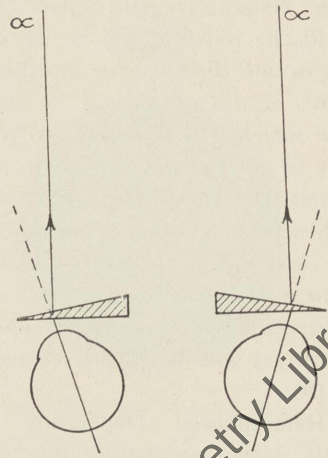


Fig. 106.—Exophoria and its Correction by Prisms.

usually in those who use their accommodation but little, that is, in myopes; it also occurs in those who put on hypermetropic or presbyopic correcting glasses for the first time, and therefore are suddenly relieved of an accommodative strain.

If it is due to a convergence-insufficiency, the exophoria is increased for near vision. Indeed in the normal person, exophoria is the rule at the near point, for convergence practically always lags behind accommodation. If an object at the near point is fixed binocularly and one eye is then

Digitized by Illinois College of Optometry Library

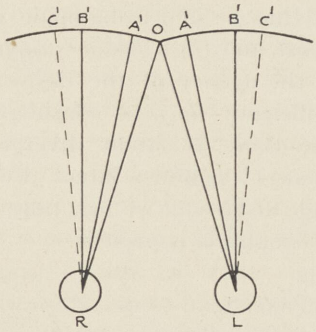


Fig. 107.—Convergence and Fusion.

The object O is at the near point of convergence. At the position C′ the eyes are in the position of rest, which is usually one of slight divergence. At the position B′ they are directed straight forwards. When converging for O, the distance B′A′ is the range of accommodative convergence, and the distance A′O is the fusion supplement.

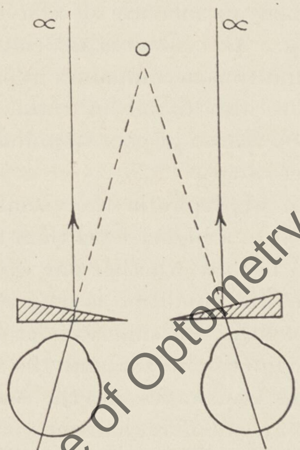


Fig. 108.—Esophoria and its Correction by Prisms.

covered, the covered eye will almost invariably deviate out ; when it is uncovered, diplopia will be experienced for a moment, and then the eye will converge appreciably until binocular vision is again regained. The normal amplitude of

Digitized by Illinois College of Optometry Library

convergence may thus be said to be made up of (*a*) *accommodative convergence* and (*b*) a *fusion supplement*, the latter being added by the agency of the desire for fusion (Fig. 107). This insufficiency may be considered physiological. Where, however, there is latent divergence for distant vision of more than 1° *d*, and a latent divergence of more than 1 metre angle at 25 cm., we can take it that a pathological degree of exophoria is present.

Esophoria (Fig. 108) is also a common condition wherein the visual axes tend to deviate inwards. It may be due to a divergence-insufficiency, in which case it is more marked for distant vision than for near. Usually it is due to an excess of convergence, in which case it is most pronounced for near vision. As such, it tends to give rise to few symptoms ; in fact it may be in some respects an advantage, for in our civilisation most visual activities are undertaken for near work, when an increase of convergence is sometimes a good thing. As a rule it is associated with excessive accommodation, and thus accompanies hypermetropic states of refraction. It is also found in those whose vision is rendered difficult by reason of poor illumination, opacities in the media, or other causes.

Hyperphoria.—In hyperphoria the visual axis of one eye tends to be directed to a higher level than that of the other. It is impossible to be sure whether one eye is raised or the other lowered, since the condition is only relative. There is thus a deficiency of either the superior rectus and the inferior oblique, or of the inferior rectus and the superior oblique. In order to force the visual axes into the correct position it is therefore necessary to call more than one muscle into activity, and the adjustment in the different positions of the eyes becomes a complex matter. It will be readily understood, therefore, that a very small divergence of this nature will give rise to considerable discomfort, and that the symptoms will be more pronounced than in the more simple anomalies of convergence and divergence.

Digitized by Illinois College of Optometry Library

Cyclophoria.—In cyclophoria the eye is twisted about an antero-posterior axis so that the vertical meridian of the cornea is deviated from the normal. When the upper end of this meridian leans towards the temple the movement is called *extorsion ;* and the muscle which is primarily concerned is the inferior oblique. A leaning of the upper end of the meridian in the opposite direction, that is, towards the nose, is called *intorsion*, a movement which is accomplished by the superior oblique.

A considerable amount of "pseudo-cyclophoria" is frequently associated with oblique astigmatism. When a patient suffering from this condition looks at a vertical or horizontal line, the image formed on the retina will lean in the direction of the maximal corneal meridian. To bring the image into its proper alignment, one or other of the obliques will be called into play. A corrective torsion of this nature therefore tends to become a life habit in cases of uncorrected oblique astigmatism, and it probably explains to some extent the distressing symptoms to which this refractive condition so frequently gives rise. It also explains the great discomfort which may result from an error in the direction of the axis of a cylinder in spectacles. With the proper correction of oblique astigmatism, of course, all symptoms of this nature disappear.

Another common type of cyclophoria occurs with near work when the lower part of the visual field is used ; indeed, Meissner has shown that if the object is very close to the eye such a condition is physiological. In these conditions the eyes are converged and rotated downwards : the first movement is accomplished by the internal recti ; the second mainly by the inferior recti. With the downward pull of these latter muscles there is associated a certain amount of extorsion which must be counterbalanced by the intorting action of the superior obliques. When this neutralising action does not act efficiently, a certain amount of cyclophoria results ; but in this case the defect rarely gives rise to symptoms or requires treatment.

Digitized by Illinois College of Optometry Library

Essential cyclophoria, like the other types of heterophoria, is due to pathological muscular imbalance, either muscular or innervational in origin. When the superior obliques are deficient or the inferior obliques over-act, extorsion is the result; when the reverse is the case, intorsion is the result. The circumstances which determine this insufficiency or over-action are analogous to those which we have already studied as affecting the other ocular muscles. In its lesser degrees the defect is common, and as a rule does not give rise to urgent symptoms; in its higher degrees it is rare. It is fortunate that this is so, for the disturbances to which it may give rise may be very distressing, and are unfortunately not readily amenable to treatment.

Symptoms of Heterophoria.—The smaller degrees of eso- and exo-phoria are extremely common, and as a rule they give rise to no symptoms; only when the deviation is great, from 5 to 10 degrees or over, is there usually marked distress. Hyperphoria, however, involving, as we have seen, the over-activity of muscles which are not usually associated in their action, may give rise to considerable trouble even when present in very small amount; and the symptoms arising from cyclophoria may be still more marked.

Visual symptoms are often evident. Vision becomes blurred on occasion, especially at times of fatigue. This is seen in its most marked form after continued near work in cases of convergence-insufficiency. In all forms there is difficulty in gazing steadily at any object, and the discomfort is increased on any attempt to follow a moving body. Sudden bewilderments are thus apt to occur, when objects, especially moving things, become jumbled up. In all cases vision is improved and relief is obtained by closing one of the eyes. There is frequently a tendency towards adopting eccentric poses of the head, while an associated blepharospasm, or a wrinkling of the forehead is characteristic. The most acute distress is associated with high degrees of cyclophoria. Vertical lines appear deviated, the houses on either side of

Digitized by Illinois College of Optometry Library

the street, for example, appearing to fall down upon the unfortunate patient, a sensation frequently associated with pronounced reflex and labyrinthine disturbances.

In the eyes themselves there is a feeling of discomfort, and the patient is frequently conscious that the muscles are being strained, that they are not working in harmony, and that his eyes are in the habit of temporarily getting out of control. The discomfort may be accentuated into actual pain which may be referred to the muscles. Local congestion, a suffused conjunctiva and blepharitis are not uncommonly evident.

The reflex symptoms are usually marked. Headache of any kind is common. An associated labyrinthine upset gives rise to vertigo, which may lead to nausea and, on occasion, result in vomiting. Restlessness is frequently apparent in children, and in adults of unstable temperament and neurotic tendencies a neurasthenic condition may be induced, or, if it is already present, its symptoms may be accentuated. Muscular imbalance, especially when associated with an error of refraction, may thus give rise to a host of varying symptoms ; but, like the effects of errors of refraction, it is to be remembered that the subject has not been exempt from unfortunate exaggeration.

Treatment.—Orthophoria, like emmetropia, is rare. The smaller errors of muscular balance which give rise to no symptoms require no treatment : this is so especially in the horizontal deviations, but, as we have seen, is rarely applicable to hyperphoria.

Two matters must first receive attention, and when they are adequately dealt with, the heterophoria frequently gives rise to no more trouble. The *general health* must be considered. The lack of muscular equipoise is frequently less the expression of a local defect than of a general neurosis, or of physical debility, or of excessive work or worry ; and when this is the case, optical treatment should not be substituted for tonics or a change of air with a rest and a holiday,

Digitized by Illinois College of Optometry Library

accompanied by a graduated amount of suitable exercise and out-door sport. Particularly in cases of convergence-insufficiency the general state of the muscular system should receive attention, while at the same time undue strain of the affected muscles should be abolished. Near work should be severely curtailed for a period, and in children, especially when school is proving too arduous, total abstinence should be enforced by the administration of atropine.

Secondly, *errors of refraction* should be corrected fully by glasses, which should be worn constantly, for it frequently happens that when an optical fault is removed, the muscular balance returns spontaneously. To this rule there are two exceptions. When convergence-insufficiency is associated with hypermetropia, an under-correction of the refractive error will stimulate accommodation and through it the deficient convergence. Similarly, a convergence excess may be relieved in myopia by undercorrecting the error, particularly for near work, so that the accommodation is rarely if ever brought into play. The importance of the careful correction of oblique astigmatism in cyclophoria is evident.

If these measures should fail, recourse should be had to optical *gymnastic exercises*, practised not only for distant vision, but also for vision at the near point. These may be done with *adverse prisms*, that is, exercises are practised against prisms directed with their bases turned towards the direction of deviation. The patient is asked to look at an object (a point of light or a candle flame), and while his gaze is still fixed, prisms, initially weak and gradually increasing in strength, are placed before the eyes at intervals of five seconds, the patient being encouraged to fuse the two images into one. These exercises may be continued at home. The patient is given a 2° prism with which to practise for a week, and this may well be augmented by 1° at weekly intervals. Meantime the surgeon assesses the progress made at each successive visit and graduates the additions accordingly. These exercises are done for distant

Digitized by Illinois College of Optometry Library

vision, and then the object is brought nearer and exercises at the near point and far point are alternated. With the head maintaining its original position, the object is then carried to the sides, and the exercises repeated until the patient can secure a single image in all parts of the room in spite of the action of the prisms. Exercises of convergence may also be practised without prisms. While reading, the patient brings the book nearer and nearer until the print becomes blurred ; he then carries it away a little, and repeats the process over and over again, every now and then relaxing his convergence by looking up from the book and gazing into the distance for some seconds.

In cyclophoria the torsion of the eye is exercised by using two Maddox rods placed perpendicularly, one in front of either eye ; in this case two red lines are seen, and instead of running horizontally, they are inclined at an angle whose size varies with the degree of the defect. One of the rods is then rotated until the two lines are fused, and then it is moved alternately backwards and forwards in the direction which will exercise the muscle, the patient meantime trying to keep the line of light from doubling. To exercise the superior obliques the rods should be rotated towards the upper nasal quadrants ; to exercise the inferior obliques, they should be rotated in the upper temporal quadrants. According to the same principles, exercises may be carried out with two lines drawn on stereoscopic cards and inserted into an amblyoscope so that they can be rotated round the one against the other ; this procedure has the advantage that the patient can practise it at home.

To be of value, these exercises must be continued for a considerable period, and even then their results are sometimes disappointing. They may succeed, however, in relieving the symptoms, although they leave the amount of heterophoria substantially unchanged. They are particularly good in exophoria, especially in convergence-insufficiency. In esophoria they are usually less successful, although the use

Digitized by Illinois College of Optometry Library

of diverging prisms at the near point in cases of convergence excess is frequently useful. In cases of hyperphoria such exercises are generally useless. In cyclophoria, although little can be promised from them, they do on occasion relieve the symptoms. In all cases, however, they should be given a persistent trial, if only because optical methods of treatment are rarely practicable and are seldom successful.

While the rational treatment is undoubtedly to strengthen the inadequate muscles with graded exercises against adverse prisms, relief of the symptoms may be obtained by the *prescription of relieving prisms,* which correct the defect optically. The base of the prism is placed in the direction of action of the muscle which is to be aided, and its apex towards that of the antagonistic muscle which is to be neutralised. The treatment is not ideal, for it may tend to perpetuate and even to increase the error which it is designed to correct: prisms, bases in, will produce a convergence-insufficiency, while prisms, bases out, will tend to establish a convergence-excess. At most their employment should be looked upon as a temporary measure, and at a later period a determined effort should be made to weaken them gradually. To this rule hyperphoria forms an exception, and no hesitation may be felt in correcting it if it is causing symptoms: the error is usually small (about 4° to 6°) and prisms can be prescribed for continuous use. In esophoria giving rise to symptoms, the temporary employment of prisms, bases out, is legitimate, and on occasion may give rise to very considerable relief, especially in young adults. In exophoria, they are, as a rule, inadvisable for distance use, but prisms, bases in, may bring considerable relief in near work by bringing the point of intersection of the visual axes closer to the eye in cases of convergence-insufficiency (see Fig. 104). Such glasses, however, should only be worn for near work.

It is to be remembered that treatment by prisms does not cure, but merely relieves; and therefore, other things being

Digitized by Illinois College of Optometry Library

equal, the smallest correction which brings relief should be given. Hyperphoria, however, may be fully corrected. Thus if there is 10° of eso- or exophoria, the full correction would take away all stimulus for the external or internal recti to function adequately, and a further development of convergence-excess or deficiency would tend to develop. An under-correction should therefore be made always, which by leaving the muscle with some, although not an excessive amount of work to do, will not have the same tendency to perpetuate the condition. More than half the defect need rarely be corrected in order to give relief; thus a deviation of 10° will probably require a correction of 5°, and the prisms are divided between the two eyes equally, each receiving a correction of 2·5°. The prisms are combined with lenses which correct the refractive error; and where the deviation is small, the same effect may be produced by decentring the lenses (see p. 353).

Little can be done for the distressing condition of cyclophoria, for no optical device can correct the deviation. The adequate correction of the refraction is essential, and it is significant that, if hyperphoria is present, which is frequently the case, its correction frequently brings relief of all the symptoms. Apart from this, the distress of the effects of torsion can be alleviated by using "rest cylinders" of small power (say 0·5 D) placed at an angle between 45° and 90° in the right eye and between 90° and 135° in the left, in non-astigmatic cases, and by moving the cylinder in astigmatic cases in a similar direction (about 5° for each 1 D cyl.). This expedient, however, has much to be said against it. As with the use of prisms in imbalance of the recti, the introduction of cylinders does nothing to strengthen the muscles involved, and, if anything, tends to perpetuate the deformity. Moreover, if a vertical deviation is overcome, it is done at the cost of disturbing horizontal lines, and, in addition, the astigmatic effect blurs the vision. An incorrect cylinder may indeed bring on all the symptoms of eye-strain,

Digitized by Illinois College of Optometry Library

with the result that a greater evil is treated by introducing a lesser.

Owing to their weight and the distortion which they produce, it is not usually advisable to prescribe prisms stronger than 3° for each eye. Where much higher degrees of deviation are present, the condition may require to be relieved by operative measures, such as a muscular recession or an advancement, but the necessity or advisability of this procedure is rare. The technique of these operations is outside the scope of the refractionist as such. It is important, however, to remember that an excess of power in a muscle should always be corrected by a recession, and a deficiency of power by an advancement. Moreover, if operative treatment is to be undertaken, it is essential that a comparable deviation should exist for all distances, lest, for example, a pronounced esophoria for close work is treated only to produce as serious an exophoria for distance.

When a pronounced degree of insufficiency or excess of power in one of the lateral muscles has been diagnosed, the operative correction of eso- and exophoria is a straightforward matter. Hyperphoria should be corrected, in the very rare cases where it would be advisable, by operating upon the superior or inferior recti. Cyclophoria, however, presents a more complicated problem. The inaccessibility of the obliques makes surgical intervention with the muscles directly concerned impossible, and any interference should be limited to the recti. Either the vertical or the horizontal recti may be chosen: for example, an extorsion due to insufficiency of the superior oblique may be corrected by a tenotomy of the nasal fibres of the superior rectus or preferably by an advancement of the nasal side of the inferior rectus, while the same result may be obtained by advancing the upper border and receding the lower border of the internal rectus. Since the vertical recti work synergically with the obliques, it seems more logical that their attachments should be altered than that the external or internal recti, which are

Digitized by Illinois College of Optometry Library

simple rotators, should be saddled with the entirely new function of torsion. Preference should therefore be given to the vertical recti in uncomplicated cyclophoria. A co-existing hyperphoria makes the choice of these muscles essential; but on the other hand, if an eso- or exophoria exists, the horizontal muscles should be chosen, and the procedure undertaken should be such as will tend to relieve the whole of the imbalance. None of these cases, however, should be operated upon unless every other expedient has been tried, and unless the symptoms, in spite of this, are such as necessitate active intervention; all of them require the most careful consideration in planning the operative measures to be adopted, and the technique of a surgeon who is skilled in this specialised and difficult work.

Digitized by Illinois College of Optometry Library

CHAPTER XVII

HETEROTROPIA

In the condition of heterotropia, or squint, the deviation of the eyes from parallelism is not overcome by involuntary effort and remains apparent. This may be due to the magnitude of the error, as is seen in its most decided form when a muscle is paralysed; it may also be due to a deficiency in the cerebral co-ordination of the images from the two eyes, or it may result from an inequality of the visual acuity making binocular vision useless or impossible. The result is that one eye alone is used for fixation while the other deviates away from the line of vision. If both the peripheral organ and the central mechanism are well developed, the result is diplopia with all its discomforts and annoyances; if one or other of these is deficient, there is a strong tendency to suppress the image of the deviating eye, a process which, if persisted in, tends to lead to some degree of amblyopia of that eye. In addition, there is always present the disfiguring appearance of a squint,

So disfiguring is this effect that the condition of squint has been recognised from the earliest times, and its history is full of interesting sidelights. It was—and still is—considered an affliction sent by an angry god, and the ill-luck brought by the look from a cross-eyed person forms the basis of many legends. Hippocrates, Celsus, and Galen knew of the condition; the great Frenchman, Ambroise Paré, spent much time over it, and recommended as treatment the wearing of horn spectacles with central perforations, in the hope that the two eyes might be induced to look through the central holes. In the beginning of the eighteenth century the bombastic itinerant Englishman, John Taylor, travelled with a military guard throughout the courts of Europe, working "miracles" by its operative cure. Rational treatment was inaugurated by Buffon, in 1743, who suggested the occlusion of the sound eye in order to force the squinting eye into

Digitized by Illinois College of Optometry Library

use ; its dependence upon refractive and accommodative anomalies was stressed by Donders, of Utrecht, in 1864, who insisted upon its treatment by glasses ; while in the beginning of this century, Claude Worth, of London, turned attention upon the cerebral element of fusion and put treatment by visual training methods upon a sound foundation. Treatment by operative measures was also of gradual growth. Delpech, in 1816, described the technique and advantages of tenotomy of the tendo Achilles, and in 1827, Anthony White suggested an application of the same principle to the eye. This was attempted—unsuccessfully—by Pauli, of Landeau, and the first authentic success appears to have been at the hands of Dieffenbach, of Berlin, in 1839. The disastrous results of indiscriminate muscle-cutting prompted von Graefe to introduce the operation of advancement of the weaker muscle in 1857, the same year in which George Critchett, of London, described the "three-stitch operation" upon which most subsequent procedures have been based.

Paralytic Strabismus.—A paralytic squint, wherein the deviation of the eyes is produced by the paralysis of one or more of the ocular muscles, seldom comes within the province of the devices of the refractionist. He is concerned with those deformities which are caused by a lack of muscular equilibrium or by a deficiency of vision, and which are susceptible to amelioration or cure by optical and educational methods. The differential diagnosis between the two types is, however, important, in order that he may determine that with which he is dealing. In a paralytic squint, the relative position of the two eyes differs with every movement of the eyes in which the paralysed muscles are concerned. When the eyes are in the primary position and are directed straight in front, there may be a slight deviation away from the direction of action of the affected muscle, since the abolition of the tone of this muscle disturbs the condition of equipoise. When the eyes are turned away from the paralysed muscle, the normal antagonists have free play and little or no deviation may be evident ; but when they are turned in the direction of action of this muscle, movement is limited or absent, and the deviation becomes maximal. In a non-paralytic squint, the visual axes, although abnormally directed, retain the same abnormal relation to each other in

Digitized by Illinois College of Optometry Library

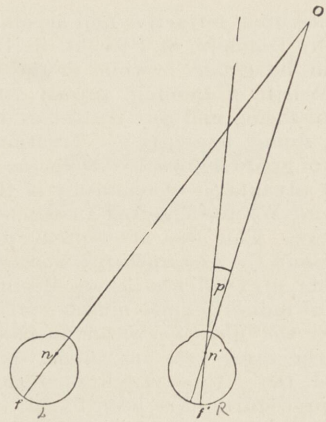


FIG. 109.—PRIMARY DEVIATION IN PARALYTIC STRABISMUS.

Primary deviation in paralysis of the right external rectus. n and n' represent the left and right nodal points; f and f', the maculae. O is the object looked at. p is the angle of primary deviation.

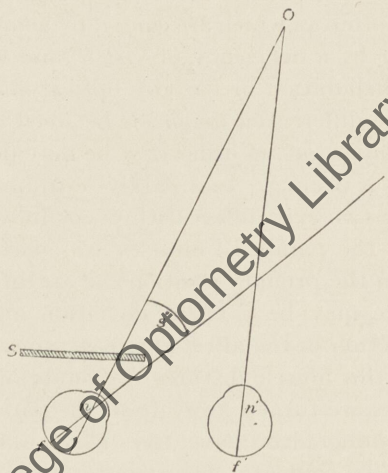


FIG. 110.—SECONDARY DEVIATION IN PARALYTIC STRABISMUS.

Secondary deviation in paralysis of the right external rectus. n and n', the left and right nodal points; f and f', the maculae, S, the screen in front of the left eye; s, the angle of secondary deviation, is seen to be greater than p, the angle of primary deviation in Fig. 109.

Digitized by Illinois College of Optometry Library

all movements of the eyes. Since both eyes thus move together such a squint is called *concomitant.*

The difference between the two types can be detected in a rough and ready way by asking the patient to look at the surgeon's finger held about 50 cm. away, and to follow the movements of the finger in all directions (to either side and up and down) while he keeps his head still. Any obvious disorientation between the two eyes is thus rendered apparent.

The most delicate test is conducted thus. The patient is asked

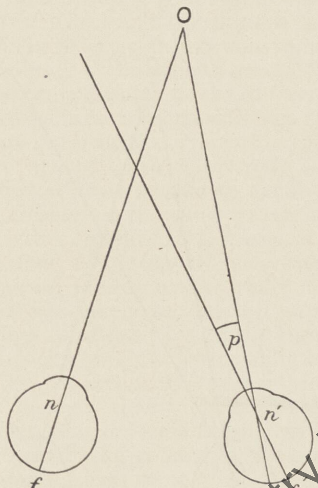


Fig. 111.—Primary Deviation in Concomitant Strabismus.

The notation is as in Fig. 109. *p* is the angle of primary deviation.

to fix an object some distance away, and the squinting eye is covered with a card. The deviation of this eye is observed. This is called the *primary deviation* (Fig. 109). The sound eye is then covered up by the card, and fixation is assumed by the affected eye. The deviation in the sound eye is now observed. In the attempt to get the affected eye into line, if one of the muscles is paralysed, an abnormal effort will be made to try to move it in the direction of the paralysed muscle. This energy is involuntarily equally distributed between the two eyes, and therefore the corresponding muscle on the other side will be over-stimulated and its movement in this direction will be excessive. This is called the *secondary deviation* (Fig. 110). In a paralytic squint,

Digitized by Illinois College of Optometry Library

therefore, the primary deviation of the affected eye is less than the secondary deviation of the sound eye; whereas in concomitant squint the two deviations are equal (Fig. 111 and 112.)

The Symptoms of a paralytic squint are:

(1) *Limitation of movement* of the affected eye in the direction of action of the paralysed muscle;

(2) *Diplopia*, which is most marked in the direction of action of the paralysed muscle;

(3) *Altered position of the head*, so that the eyes are orientated in the direction of least diplopia.

The diagnosis of the affected muscle is most easily determined

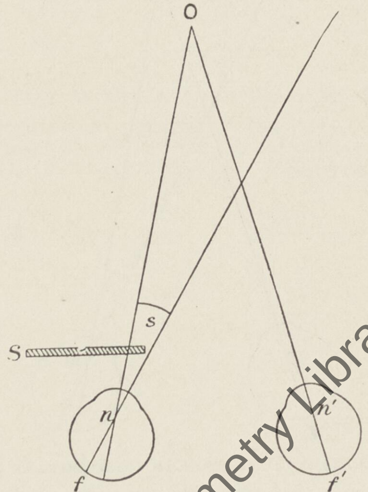


Fig. 112.—Secondary Deviation in Concomitant Strabismus.

The notation is the same as in Fig. 110. *s*, the angle of secondary deviation, is equal to *p*, the angle of primary deviation in Fig. 111.

from the scheme suggested by Maddox. The movements of the eyes are controlled by the following groups of muscles:

(1) *Lateral*.—(*a*) *R*.—R. ext. rectus, and L. int. rectus.
(*b*) *L*.—L. ext. rectus and R. int. rectus.

(2) *Elevators*.—(*a*) *R*.—R. sup. rectus, and L. inf. oblique.
(*b*) *L*.—L. sup. rectus, and R. inf. oblique.

(3) *Depressors*.—(*a*) *R*.—R. inf. rectus, and L. sup. oblique.
(*b*) *L*.—L. inf. rectus, and R. sup. oblique.

The patient's field of vision is divided into areas thus:

Digitized by Illinois College of Optometry Library

Left. Sup.		Right. Sup.
Left. Ext.		Right. Ext.
Left. Inf.		Right. Inf.

A green glass is placed in the trial frame before one eye, and a red glass before the other, and the patient looks at a luminous object, such as the light of a self-luminous ophthalmoscope. The one eye sees a red image ; the other a green. The light is moved outwards from the central point to the different areas of the field of vision, and the area is thus found wherein the greatest separation of the two images occurs. From this the muscles involved in the movement are at once identified, since (in Maddox's words) " the condition must be due to a failure in the action of the same-named muscle, or the most cross-named muscle " (or contrary-named) with reference to the area involved.

Thus if the greatest displacement occurs in the left external area, the left external rectus, or the right internal rectus is at fault; if in the left superior area, the left superior rectus or the right inferior oblique is at fault ; if in the right inferior area, the right inferior rectus or the left superior oblique ; and so on.

Which of the two muscles in the pair incriminated is at fault, is determined by the fact that the " image that lies farthest in the direction of increasing diplopia belongs to the paralysed eye." The image which is farthest displaced is, of course, easily identified with the corresponding eye, as it is of the same colour (red or green) as the glass before that eye. Thus if the greater displacement occurs in the left external area, and the green image is farthest out, if the green glass is before the right eye, the right internal rectus is paralysed.

The treatment of paralytic strabismus is essentially medical, directed to the cause. Should optical aid be required in a chronic case, an attempt may be made to correct the deformity by prisms. In this case separate corrections will almost certainly be required for distant vision and for near vision. In none but the milder cases can much help be given ; and in no case can complete relief be obtained, since the amount of deviation varies in different parts of the field. This, however, may be overcome to some extent by the patient if he learns to move his head rather than his eyes. In most cases in which the deviation and the symptoms are marked, it is best to have recourse to a shade over the squinting eye, or to advise spectacles provided with one ground glass, so

Digitized by Illinois College of Optometry Library

that, by excluding the vision of one eye, the very distressing symptom of diplopia is eliminated.

Kinetic strabismus is a rare condition caused by the spastic action of one of the muscles. The deviation is usually sudden in onset and temporary in duration, and is most marked when the affected muscle is called into action. It is caused by irritative lesions in the central nervous system, such as meningitis, and tumours of the mid-brain and cerebellum.

The Ætiology of Concomitant Strabismus.—We have seen that the three essentials which are necessary for perfect binocular vision are the production of two approximately equal images on two efficiently functioning maculae, muscular equipoise, and an adequate cerebral mechanism to co-ordinate and interpret the two sets of impressions. Whenever any of these is gravely deficient binocular vision becomes impossible, and, deprived of the stimulus for fusion, the eyes tend to deviate away from their proper alignment with a resultant squint.

Under the first head are included a great variety of causes of defective vision: opacities in the media of one eye, diseases of the fundus, or a difference in refraction between the two eyes so great that the disparity between the two images cannot be neglected. There are also cases where the vision of one eye is defective beyond any explanation which the objective findings provide. There is reason to believe that the defect exists from birth, and its cause, while it remains quite unelucidated, is usually taken to be of the nature of a congenital defect. It is described as *congenital amblyopia* (ἀμβλύς, blunt; ὤψ, eye), and is to be distinguished from a similar condition which results from continued psychical repression of the image of one eye (*amblyopia ex anopsia*), which will be noticed presently. The occurrence of such a congenital condition is, of course, largely conjectural, and it is possible that many of those cases can be explained otherwise. It has been lately pointed out, for example, that retinal hæmorrhages of all grades of severity are very common at birth, and while most of them clear up

Digitized by Illinois College of Optometry Library

leaving no trace of their presence and no functional impairment, it is reasonable to imagine that sufficient damage may be done occasionally to the macula or the papillo-macular bundle of fibres to cause permanent weakening or even loss of central vision. This may account for many of these cases; and other explanations may be eventually forthcoming. When failure of vision in one eye is the determining cause of squint, especially when it develops late in life, there is a tendency for the squinting eye to assume the position of rest, that is, it deviates outwards.

Defective muscle balance of any kind may progress beyond the limits of heterophoria and lead to the development of squint, but the most common muscular anomaly which figures in the ætiology is a dissociation between accommodation and convergence. It will be remembered that a hypermetrope has to use his accommodation in excess of his convergence. Thus a hypermetrope of + 2 D has to employ 2 D of accommodation to see distant objects; in order to see an object clearly which is situated $\frac{1}{4}$ metre away, he has to requisition another 4 D, that is, he uses 6 D of accommodation while at the same time he ought to use only 4 metre angles of convergence. Physiologically, the amount of accommodation and convergence should be equal, but were he to employ them equally, he would be faced with the dilemma of either using 4 D only of accommodation, when he would be converging accurately but not seeing distinctly, or of using 6 metre angles of convergence, in which case he would be seeing clearly but converging too much. Since the dominant desire is that of clear vision, he adopts the latter alternative and develops a converging squint. Contrariwise, a myope uses his convergence in excess of his accommodation. If he has a refractive error of − 2 D and wishes to look at an object 0·25 metre away, he requires only 2 D of accommodation instead of 4, and similarly tends to use only 2 metre angles of convergence; he therefore develops a diverging squint. In each case the tendency is for the better

Digitized by Illinois College of Optometry Library

eye only of the two to be employed, and the vision of the other is therefore sacrificed.

The sacrifice is made all the more easily if the vision of the other is in any way defective, or if the fusion faculty is not well developed. Those persons who have already developed binocular vision will not readily abandon its advantages, and they will undergo considerable strain in dissociating accommodation and convergence in order to retain it. These cases, as we have seen, are the subjects of heterophoria. It is when the stimulus for fusion is lacking that heterotropia results.

This can be simply seen in the following way: If an emmetrope looks at a distant object, and two spheres of — 4 D are placed in front of his eyes, he will still be able to see it by exercising + 4 D of accommodation. His convergence is, however, unchanged, and the effort to see clearly produces a feeling of strain and giddiness; this is heterophoria. Any attempt to increase the accommodation beyond 4 D will probably result in the image becoming indistinct, for the limit of dissociation from convergence has been reached, and the desire for binocular vision is greater than that for clear images. If, however, a coloured glass is placed before one eye, thus taking away the possibility of binocular vision, diplopia is at once produced and this eye deviates; this is heterotropia.

There are many circumstances which point to the dissociation between accommodation and convergence as having much to do with the development of squint. Converging strabismus is nearly always associated with hypermetropia, and diverging strabismus with myopia, and there is a tendency when the accommodation is paralysed with atropine or the refractive error is corrected by glasses for the deformity to be ameliorated or cured. The condition almost invariably commences in childhood, usually in infancy, before the fusion faculty is fully developed. Between the ages of two and six is the most usual period for the appearance of converging strabismus, just at the time when accommodation is first seriously called into play, for the interest of the child has begun to be attracted by near objects, such as picture books and toys. Its commencement is

Digitized by Illinois College of Optometry Library

frequently preceded by a debilitating illness, as measles or whooping cough, which may be expected to lower the general muscular tone. Moreover, the deformity undoubtedly tends to diminish with age, and it may be more than incidental that the amplitude of accommodation does likewise. Diverging squint, on the other hand, is not usually met with at such an early stage, and it is significant that myopia is not congenital but develops in the growing period of youth. Unlike convergent squint, it tends, if anything, to increase with age. When the myopia is high, the working distance becomes so near that any attempt to obtain sufficient convergence is impossible, and consequently one eye only is used while the other assumes the position of rest and diverges. The tendency is also increased by the anatomical considerations, such as the shape of the orbits in association with the length of the eye-balls. It is to be remembered, however, that every ametrope does not by any means squint, nor is every case of strabismus associated with anomalies of refraction or disturbances of accommodation; moreover, hypermetropes may develop a diverging squint, and myopes are not uncommon who have a converging squint. It would therefore appear that although their influence is undoubtedly important, these considerations are by no means the sole factors in the ætiology.

The third important determinant in the ætiology of squint is the state of development of the reflex paths which coordinate binocular vision. We have seen that when these are functioning adequately, a dissociation between the two eyes is rare; and the readiness with which a strabismus develops depends directly upon the extent to which binocular vision has been acquired at the time when the impetus towards disorientation makes itself felt.

The sequence of events in the development of the usual case of strabismus is therefore as follows: we will take as an example a convergent squint. A child with hypermetropia on first turning his attention to near objects has

Digitized by Illinois College of Optometry Library

to use an excess of convergence, and develops a condition of spasmodic esophoria. This gradually increases until binocular fixation for near objects becomes difficult or impossible, and the esophoria for near objects becomes a true periodic converging squint. Further progression involves an esophoria and then a squint for distant objects also, a change due largely to the addition of a divergence-insufficiency to the initial condition of convergence-excess. Lastly, secondary muscular changes occur — a hypertrophy and contracture of the internal rectus and a stretching and weakening of the external—and these produce an absolute reduction of the power of rotation outwards and an excess of rotation inwards. Such changes in the muscles are usually of late development, although some rare cases of squint may be originally due to a muscular defect. As a general rule the original cause of the disturbance is central, and follows the law, promulgated by Sherrington, that excessive stimulation of one centre is accompanied by the inhibition of the activity of the centre controlling the opposing function. For this reason a convergence-excess leads readily to a divergence-insufficiency, while secondary hypertrophies and atrophies of the peripheral muscles increase and perpetuate the tendency at a later date.

The Vision in Concomitant Strabismus.—Originally in early childhood, it is probably the case that diplopia accompanies all cases of squint. At a very early stage, however, the disadvantages of double vision lead to the suppression of the images of the deviating eye. This suppression is psychological, but after it has been practised for some time, the delicacy of functioning of the eye becomes impaired and the visual acuity deteriorates progressively. A more or less pronounced degree of this condition of *amblyopia* or *anopsia* is evident in practically all cases of long-standing strabismus, and all power of fixation may ultimately be lost by the squinting eye. It may be found difficult or impossible to regain this loss of vision, especially if

Digitized by Illinois College of Optometry Library

it has persisted for some time. Cases of partial recovery have, it is true, been reported, but these are rare ; and the prevention of the occurrence of this type of blindness to an irremediable degree is the strongest argument for the early and efficient treatment of every case of squint. It is obvious that such an amblyopia is largely cerebral in origin and is essentially a purposive repression rather than a passive consequence of mere lack of use of the retina or facilitation of the central nervous paths. Thus patients with congenital cataract in whom the retina has never been used, may obtain good vision if operated on later in life ; and in middle age a cataract may be removed after it has existed twenty years or more, without any deleterious results in the functioning of the retina.

Difficulties may arise after the operative treatment of such cases. The image in the squinting eye has been accustomed to fall, not upon the macula, but upon an eccentric point to one or other side of it. Ultimately the acuity of vision in this *false macula* may become greater than that in the true anatomical one, and, if the deviation is righted so that the images now fall upon the latter, the useful vision is impaired. Indeed, the false macula from long custom may have become the functional centre of the retina, and the true macula from disuse may have sunk to the secondary status of the peripheral retina. If this acquired relation persists after the sudden change of position entailed by the operation, the images received may be disorientated and diplopia result. Double vision may also arise from another cause. The impressions received by the eccentric macula have been accustomed to being suppressed : and as the process of suppression appears in some respects to be regional, when the squint is rectified and another part of the retina is suddenly made use of, the exclusion of the images therefrom may be less complete, and diplopia may result. As a rule such a diplopia gradually diminishes and disappears ; but on occasion it persists and is a cause of great discomfort to the patient.

Digitized by Illinois College of Optometry Library

Varieties of Heterotropia.—According to the direction of deviation of the squinting eye, a classification of heterotropia may be used similar to that employed in heterophoria. *Esotropia* implies a converging strabismus; *exotropia* a diverging strabismus, and *hypertropia* a vertical deviation. Since this last term is relative, it may be further differentiated as *strabismus sursum-vergens*, where the eye moves upwards, and *strabismus dorsum-vergens* where the eye moves downwards.

Depending on the occurrence of the squint, the following classification is also employed. If the deviation always occurs in one eye the condition is called *unilateral strabismus;* if either eye squints on occasion, the term *alternating strabismus* is employed. In the first case fixation is lost by the squinting eye; in the second it is retained. In both types the deformity may be apparent at some times and disappear at others, the development of the squint being determined by considerations such as the degree of convergence employed, or the state of muscular fatigue. These are differentiated as *constant* and *periodic strabismus.*

Treatment.—The ideal treatment of a squint is to correct the deformity and to bring about the restoration of binocular vision. We have seen that the laying down of the reflex pathways which subserve this function is difficult by educational means before the age of six, is more difficult between six and seven, and is quite impossible at a later stage. It will therefore be realised that the first essential in treatment is to commence active measures at the very earliest moment possible in every case, making no delay from the first time that the squint is noticed. It is only by adopting this policy that success can be anticipated, or any improvement other than cosmetic can be gained. The popular impression, not only among the laity but also among medical practitioners, that a child will "grow out" of the deformity, cannot be too strongly condemned, and has

Digitized by Illinois College of Optometry Library

been responsible for the development of many functionally useless eyes.

The first thing which must be done is to *determine and correct the refractive error.* This should be done under full cycloplegia, atropine having been given for at least three days prior to the examination. A full correction should be ordered, deducting for the effect of the atropine not more than 1 D, preferably about 0·5 D ; and if the glasses are tolerated with difficulty, atropine may be continued for some weeks until the child gets used to them. In determining the error, reliance should be placed upon the retinoscopy rather than on any subjective results, while any astigmatic error, especially in the squinting eye, should receive minute attention. A retinoscopy can be done in all cases, for the youngest child will fix a light, and the test lenses can be held in the hand at arm's length, thus doing away with the necessity of trial frames.

It should be established as a ritual that the glasses be worn constantly : they should be put on first thing in the morning and taken off last thing at night, and in young children who attempt to push them off, they should be tied on (see p. 338). Most squints develop between the ages of two and six, and most children of two can be induced to wear glasses. Under this age the most practicable course to adopt is to keep the child mildly under the influence of atropine, prescribing it as an ointment once a day, or every second day, until the wearing of a glass is possible.

In some cases the effect of abolishing the accommodation by atropine rectifies the squint, and in these the deformity is usually kept under control by glasses.

As soon as the optical defect has been corrected, the *vision in the squinting eye should be encouraged* and every endeavour made to improve it. The acuity of vision is measured in the ordinary way in older children, but if the patient can neither read letters nor appreciate pictorial test types, Worth's ivory ball test (p. 265) may provide some information. The child

Digitized by Illinois College of Optometry Library

should be seen soon after the glasses have been given, and the vision estimated again. If the squinting eye is amblyopic or if its acuity of vision is defective, it should be forced into use by occluding the sound eye. The most drastic method is to cover up the squinting eye completely by tying on a pad or placing some cotton wool between the eye and the glass, so that the eye is closed. If the child tries to push the pad away, it can be strapped on all round the edges. If the eye appears to be completely amblyopic, it may be advisable to attempt this for the first month. The most practicable method to adopt, however, is to keep the better eye under the influence of atropine, so that while distant vision usually becomes indistinct with this eye, near vision becomes impossible. The defective eye is thus coerced into activity, and the continuous exercise thus forced upon it improves its efficiency to a considerable extent in many cases. At the same time a constant watch should be maintained over the progress of the case, since the deviation sometimes becomes transferred to the atropinised eye and the vision in it may deteriorate.

The results of such treatment are very varying. If the eye was amblyopic before treatment commenced, it usually remains so in spite of it. In any case, it should be occluded for a month, and if no improvement occurs a further month may be tried. If this too proves fruitless, all hope of its ultimate functional utility may be abandoned. If any vision can be elicited, a course of atropinisation should be inaugurated. Provided the case is carefully supervised, there need be no hesitation in continuing this for considerable periods of time, as long as any improvement is noticed. The ideal to be aimed at is to persist until the vision in the two eyes is approximately equal, or until no further improvement is obtained. At this stage, in favourable cases, equality of vision is usually marked by the squint becoming alternating, one or other eye being used indiscriminately for fixation.

Digitized by Illinois College of Optometry Library

As soon as adequate vision in the two eyes is secured, an attempt should be made to develop binocular vision by *orthoptic treatment.* In those cases where the vision in the squinting eye is useful when the case is first seen, this should, of course, be inaugurated from the first. The attainment of true binocular vision is the ultimate aim of all treatment, and once it is established a permanent cure may be considered to have been effected. Unfortunately the application of such treatment is very limited. In the first place, it must be begun early, before the age of six. In all cases it is extremely tedious, and demands an amount of perseverance

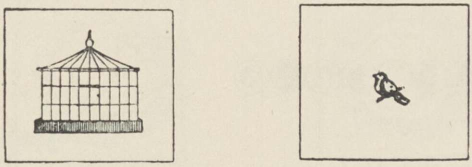


FIG. 113.—AMBLYOSCOPIC PICTURES.
To train simultaneous perception.

and patience and time which are not always available. Even under the best conditions its results are often meagre, and unless the best conditions are present any attempt to employ it profitably is useless. It is seldom possible to initiate a true stereoscopic faculty by education in this way; the most that can be hoped with any degree of certainty is to develop a fusion faculty that is deficient.

The methods employed are something after the following. A stereoscope of some form is used, the best being a Worth's amblyoscope which is fitted with a vertical adjustment (as suggested by Nelson Black) as well as a horizontal, and in which the brilliance of illumination can be graded so as to vary the brightness of the image presented to the two eyes either by altering the resistance on the lamps or by the interposition of smoked glass diaphragms of varying opacities (see p. 210).

Digitized by Illinois College of Optometry Library

The child is placed on the surgeon's knees, the amblyoscope adjusted so as to correspond roughly with the angle of the squint, and two object-slides inserted which do not require fusion but only simultaneous perception. Fig. 113 is an example. Suppose the cage is before the fixing eye, and the bird before the squinting eye: the child will see the cage alone at first. He is asked to look for the bird, and the lights are so adjusted that the illumination of the deficient eye is more intense than that of the sound eye, until the bird is suddenly seen. At this point the cage will have disappeared, but

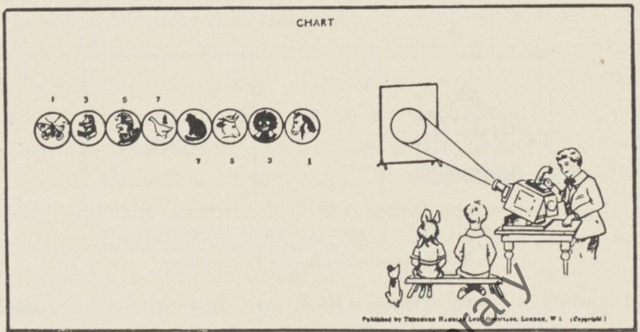


FIG. 114.—AMBLYOSCOPIC PICTURES.
To train the sense of fusion.

after careful readjustment of the lights, the two may be seen together. The child now holds the amblyoscope with both hands while the surgeon, putting his hands over the child's, converges and diverges the arms of the instrument, thus making the bird appear to go in and out of the cage. The whole matter is thus treated as a game, and the patient is taught to put the bird in the cage, the clown in the hoop, the cat on the chair, and so on.

The next stage is to pass on to object-slides which stimulate true fusion. Fig. 114 is an example. The child is encouraged to bring each successive picture upon the screen and gradually the two arms of the instrument are

Digitized by Illinois College of Optometry Library

moved over an amplitude of about 10°, the child being encouraged the while to retain the fused picture and not allow it to change its place. When this has been accomplished, he has attained the second stage in binocular vision —true fusion with some amplitude. The picture and the range of amplitude are varied, and the attempt is made to diverge and converge the two halves of the instrument more and more until the fusion faculty has been considerably exercised.

The appreciation of a third dimension is now attempted by the use of slides as Fig. 115. The impression of depth

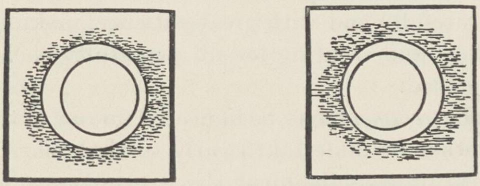


Fig. 115.—Amblyoscopic Pictures.
To train stereoscopic vision.

is extremely vivid and will be remarked upon by very young children.

The child has now gained stereoscopic vision for these conditions of illumination. The next step is gradually to equalise the illumination, which must be done without losing the newly-acquired faculty.

Another useful exercise for older children is *bar reading*. A book is read while a pencil is held between it and the eyes. Continuous reading is possible only if both eyes are employed, for the pencil cuts off a portion of the reading from each eye, and, provided the head is kept still, this can only be supplemented by the other eye. The patient thus reads with the fixing eye; for a moment the pencil acts as a screen, and if he is to see, he must use the other eye at least once in every line. At first the patient will stick at this point, then he will read with a slight hitch, and finally

Digitized by Illinois College of Optometry Library

he will read continuously and smoothly, the squinting eye taking up its share easily when it is required.

These gymnastic exercises act by stopping the process of suppression and inhibition of one image and exercising the central innervation of binocular vision by facilitating the development of reflex paths. If the child is young, a fairly strong fusion faculty may be elicited in six lessons given at weekly intervals, if the training can be efficiently continued at home by repeating the lessons for five minutes or so every day, while the surgeon notes progress at weekly intervals. The three essential points are : to begin early, to get the child interested so that it may co-operate and assist actively, and to proceed carefully and with great patience, making the training gradual and securing for all perpetuity each step that may be gained.

Operative treatment may be indicated for one of two reasons. It may either be undertaken early so that when the visual axes are in proper alignment the two images may be more easily fused, thus offering a greater prospect of the success of orthoptic treatment ; or it may be done at a later date solely for cosmetic reasons when all hope of binocular vision has been sacrificed. In all cases operation should be postponed until correcting glasses have been worn for six months and a constant amount of deviation has been reached. Thus if the original squint is of 20 degrees, and with glasses the deformity is reduced to 15 degrees, the operation must be planned to relieve the latter degree of deformity only, as otherwise, when the glasses are worn, the eyes will be overcorrected and the opposite condition produced.

When there is some indication of the possibility of the eventual success of stereoscopic exercises, operation should be undertaken early : in this case, if the education is recommenced immediately afterwards, a good result is often assured. If however, orthoptic treatment is considered hopeless or has been definitely abandoned, an operation can be performed for cosmetic purposes at any time. Unless the

Digitized by Illinois College of Optometry Library

surgeon is experienced it is most safely postponed until the age when the patient can be operated on without a general anæsthetic so that he can co-operate to give a result whose cosmetic value can be guaranteed. Under general anæsthesia the eyes deviate in the most surprising and arbitrary manner which is frequently very misleading to the surgeon ; but at the same time if he remembers the original deviation and neglects the appearance under the anæsthetic, very good results can be obtained. In any case it is all important that operation should not be postponed until the child has grown up to the age when his deformity will react unfavourably upon his mentality and make him the butt of his fellows at school. A squint is an ugly thing, and young people are pitiless and heartless to a degree. It is certainly the case that the ridicule showered upon the cross-eyed boy has led to the establishment of a soured disposition or the development of an inferiority complex which has had permanent results in later life of the most unfortunate kind in more cases than are generally recognised.

Operative treatment may involve either a *tenotomy* or an *advancement* or a *recession*. Other things being equal, of the three an advancement is to be preferred, in that its effects are more easily controlled and it leaves the muscular apparatus in a more efficient condition. A muscle which is carefully and not too extensively tenotomised, however, will re-anchor itself in a new attachment a little farther back, and give a perfectly functioning result. Too free a dissection, however, involving much of the surrounding connective tissue may give unfortunately accentuated results at a later date. If any doubt is felt on this point, a *recession* may be performed, wherein the cut tendon is anchored further back by stitches : in general a recession of 1 mm. corrects a deformity of 5 degrees.

In converging strabismus, if the deviation is less than 10 degrees, a tenotomy will be sufficient ; if it is more than 10 degrees, an advancement will be required ; if it exceeds

Digitized by Illinois College of Optometry Library

20 degrees, both operations should be combined. In diverging strabismus a tenotomy of the external rectus has a less efficient result, and usually entails a correction of not more than 5 degrees; it has therefore to be combined as a rule with an advancement of the internal muscle. In vertical deviations the operative results are more doubtful. A recession of the inferior rectus may be considered, or alternatively an advancement of the inferior rectus of the eye which deviates upwards may be performed.

Digitized by Illinois College of Optometry Library

SECTION V

CLINICAL METHODS

CHAPTER XVIII

OPHTHALMOLOGICAL EXAMINATION

No attempt should be made to correct an error of refraction by optical means until a general examination of the eyes has been undertaken and disease has been excluded. This is a principle which cannot be insisted upon too strongly, for if it is neglected, not only does the refractionist bear the responsibility of allowing appropriate treatment to be postponed until an irreparable amount of damage may have been caused and the patient gravely injured, but he will frequently find that all his efforts to improve vision by optical appliances are unavailing, and that his time has been lost in the attempt.

The history of the patient and the story of his complaint should be listened to, for it will frequently provide information and guidance of the most important kind. Thus he may be able to see in the far distance, but has trouble with reading, especially at night; or after reading for some time the print becomes indistinct, his eyes ache, and he is compelled to rest; here we suspect hypermetropia in a young person, or presbyopia in one of more advanced age. He may be able to read well, but cannot see distant objects; in which case he is probably myopic. His vision may give him no trouble at all, but symptoms of eye-strain predominate, with headaches and evidences of fatigue, suggesting a smaller refractive error probably involving astigmatism. Similar

Digitized by Illinois College of Optometry Library

or more pronounced symptoms, with a feeling of strain associated with intermittent periods of confusion or even of diplopia, may point to a state of muscular imbalance. On the other hand he may not be able to see anything clearly, when we must decide whether the imperfect vision is due to a large refractive error or to organic disease of the eye. Here the mode of onset and the duration of the trouble should be investigated.

His habits should be inquired into, for it is to suit the necessities of these that he has come for aid. His general condition should also be roughly assessed, for, as has been pointed out, a visual upset is frequently the indication of a general disturbance, and it is useless to correct the ocular error alone and leave the underlying cause of over-strain unrelieved. Such a course, it is true, may provide temporary relief, but ultimately can result only in further and more serious disturbances, or even in a complete break-down.

The general aspect of the face and eyes should be noted ; the position of the head, the symmetry of the face, the shape of the orbits, and the size of the eyes. A flat-looking face is sometimes suggestive of hypermetropia, a head elongated in its antero-posterior diameter is often associated with myopia, and a markedly asymmetrical face may indicate astigmatism. A small eye is usually hypermetropic, a large and prominent eye myopic. Small pupils are suggestive of hypermetropia, large ones of myopia.

The state of the lids and conjunctivæ should be examined, and the occurrence of blepharitis, styes, and conjunctivitis should be noted, and the ocular congestion which may denote refractive errors discriminated from the injection of inflammatory disease. The lacrimal puncta and sacs should receive attention, especially where weeping is one of the symptoms giving rise to complaint. The cornea should be examined, its transparency verified, keratic deposits looked for, and the nature of its reflex investigated. The depth of the anterior chamber should be assessed, and the clear

Digitized by Illinois College of Optometry Library

nature of its contents verified; the appearance of the iris, the shape and reactions of the pupils, and the presence of synechiae should be noted; and in all cases an estimate should be made of the intra-ocular tension.

A rough test should be made of the mobility of the eyes, and the presence or absence of squint excluded (see p. 318). Thereafter a rapid estimate should be made of the extent of the visual field. While the patient and the surgeon are confronting each other, the patient covers one eye with his hand, and the surgeon closes his (own) opposite eye. The two then look directly at each other, eye to eye, and as the surgeon moves his hand in the plane midway between them in all directions, he compares the patient's field with his own. By such means any extensive loss of the peripheral field can be quickly and easily detected.

When the patient is taken to the dark room, a similar procedure should be adopted, and the examination of the superficial parts of the eye verified with the added advantage of intense focal illumination. A preliminary examination of the interior of the eye should then be undertaken with the plane mirror, and any opacities in the media looked for and located while the eye is moved in various directions. At the same time the nature of the retinal reflex should be studied, and any inequalities in its appearance such as are indicative of retinal detachment looked for. The fundus should then be examined throughout its entire extent with the ophthalmoscope by the indirect method, which ought to be augmented by direct ophthalmoscopy, particular attention being paid to the condition of the macula and optic disc and the state of the vascular system.

All this is to be done as a matter of routine, and any pathological condition which is found should receive its appropriate treatment and the patient advised accordingly. When it does become a routine, it occupies a surprisingly small space of time, and works out much less formidably in practice than it may appear on paper. For the methods employed

Digitized by Illinois College of Optometry Library

and the interpretation of the findings obtained, text-books of clinical ophthalmology must be consulted ; the importance of the matter can only be insisted upon here. It is only when this is done and organic disease excluded that optical treatment can be undertaken with safety.

The various methods and modifications of methods which have been proposed from time to time for estimating the refraction of the eye and correcting the muscular anomalies with which we are concerned are legion ; many of them are ingenious rather than useful and practical. In the following pages only the more important ones are detailed which the writer himself teaches and upon which he has been accustomed to rely in practice.

Digitized by Illinois College of Optometry Library

CHAPTER XIX

VISUAL ACUITY

THE first step in the optical examination of a patient is the determination of his visual acuity. This, of course, is a function not only of the dioptric apparatus of the eye, but also of the retina, the nerve paths, and the central nervous mechanism. It is only with regard to the defects of vision which are due to anomalies in the first of these that we are concerned at the moment.

A convenient means of differentiating whether an impairment of vision is due to a refractive error or to a structural or organic cause is by means of the *pin-hole test.* When an opaque disc perforated by a small hole is held in front of the eye only a small pencil of rays gets through, which passes through the axis of the dioptric system and is therefore unaffected by it. It follows that if the hole were small enough all refraction would be eliminated, and a clear image would thus be formed in the same manner as is seen in the pin-hole camera (see p. 78). If, then, a patient presents himself complaining of defective vision, and doubt is felt whether the fault is due to his refraction or to organic disease, this simple test will clear up the point. He is asked to look at a distant object (the test types), and then an opaque disc perforated with a small central hole is placed in front of his eye. If vision improves, the refractive system is at fault; if it does not, then some other cause, such as opacities in the refractive media, disease of the retina, or of the central nervous system, should be suspected. In conducting the test two things are to be borne in mind. Its efficiency depends on the passage of only a few rays of light through the pin hole, and since this is the case, the illumination must be good. Secondly, care must be taken that the pin hole is opposite the centre of the pupil.

The acuity of vision is determined by the smallest retinal image whose form can be appreciated, and it is measured by the smallest object which can be clearly seen at a certain distance. In order to discriminate the form of an object its

Digitized by Illinois College of Optometry Library

several parts must be differentiated; and if two separate points are to be distinguished by the retina, it is probably necessary that two individual cones should be stimulated while the one between them remains unstimulated. Histological measurement has shown that the average diameter of a cone in the macular region is 0·004 mm.; this therefore represents the smallest distance between two cones. It thus appears that a normal eye should be able to appreciate a retinal image of this size, and although the standard varies very markedly between individuals, this estimate has on the whole been corroborated by subjective experiments.

We have seen that the further away an object is from the

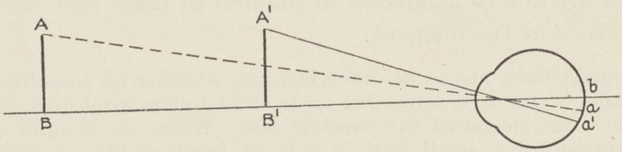


FIG. 116.—THE SIZE OF THE RETINAL IMAGE VARIES WITH THE DISTANCE AT WHICH THE OBJECT IS FROM THE EYE.

AB and A′B′ are of the same size. If A′B′ is one half of the distance of AB from the eye, the image $a'b$ will necessarily be twice the size of the image ab.

eye, the smaller will be the image formed on the retina; that is, the size of the latter is a function not only of the size of the object but also of its distance away (Fig. 116). Consequently, combining these two factors, the most convenient standard to adopt in estimating the acuity of vision is the size of the visual angle, that is, the size of the angle formed by two lines drawn from the extremities of the object through the nodal point of the eye. It is found that in order to produce an image of the minimal size of 0·004 mm., the object must subtend a visual angle of 1 minute. This, then, is taken as the standard of the normal visual acuity.

These principles have been embodied in *Snellen's Test Types*, which are now used almost universally in testing the acuity of vision. The types consist of series of letters of

Digitized by Illinois College of Optometry Library

diminishing size, as is seen in Fig. 117. Each letter is of such a shape that it can be enclosed in a square the size of

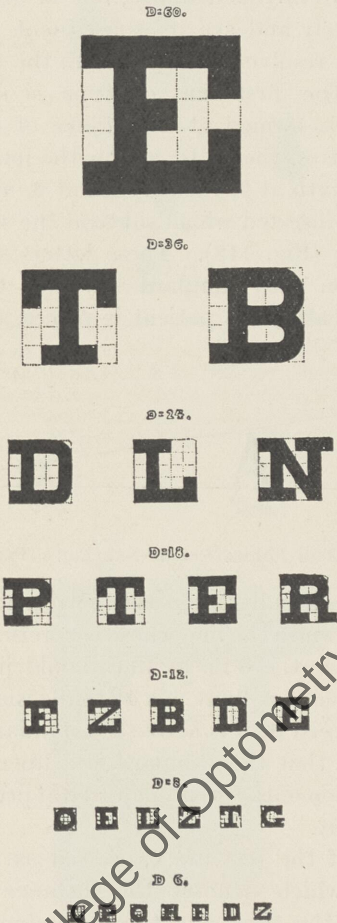


FIG. 117.—SNELLEN'S TEST TYPES.

which is five times the thickness of the lines composing the letter. The sizes of these squares, that is, the breadth of the lines, is such that their edges subtend an angle of 1 minute

Digitized by Illinois College of Optometry Library

at the nodal point of the eye when it is a certain specified distance away. Each entire letter therefore subtends an angle of 5 minutes at this distance, but in order to analyse its form completely and see its constituent parts, the eye must be able to resolve them down to the standard limit of 1 minute. The first line of type is so constructed that this angle is formed at a distance of 60 metres, the second at 36 metres, the third at 24, the fourth at 18, the fifth at 12, the sixth at 9, the seventh at 6, while additional lines are usually inserted which subtend the same angle at 5 and at 4 metres (Fig. 118). These letters should thus be read by a person with standard vision at these distances away. Consequently, if a patient is placed at a convenient

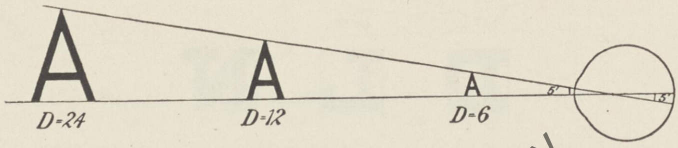


Fig. 118.—The Formation of Snellen's Test Types.

distance, which is usually taken as 6 metres, he should be able to read easily down to the line whose theoretical view point is 9 metres off, while the 6 metre line should just be distinct. If he cannot reach this limit, his distant vision is defective; and if he can exceed it, it is above the standard. In practice it will be found that the standard is a liberal one, for the acuity of the vision of the great majority of people can readily be raised above it.

The results of the test are expressed as a fraction, the numerator of which denotes the distance at which the patient is from the type, and the denominator, the line he sees at this distance. Thus if his vision is normal and he sees the line which ought to be read at 6 metres when he is 6 metres distant, his visual acuity is 6/6; if, when he is at this distance, he can only see the line which a person with

Digitized by Illinois College of Optometry Library

FIG. 119.—BOX TEST TYPES FOR CLINICAL USE.

Four different sets of letters are arranged on a revolving box whose movement is controlled by pulleys. Below the letters is a revolving disc perforated by holes of varying sizes, any of which may serve as a window to a light in the interior of the box. This is used as a point of light for Maddox's tests, etc.

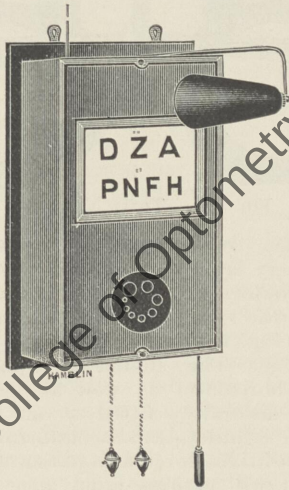


FIG. 120.—CABINET TEST TYPES FOR CLINICAL USE.

Digitized by Illinois College of Optometry Library

standard vision should see at 24 metres, his visual acuity is 6/24; while if he reads still further and reaches the line constructed to subtend the normal visual angle at 4 metres, his acuity is 6/4.

The Routine Testing of the Visual Acuity

The *test types* should be clearly printed and legible, and should not, as often is the case, be obscured by the outlines of the squares upon which they are constructed. It is essential that they be well illuminated. In order to secure uniformity of testing, the vision should be taken by artificial light. A much better contrast is obtained if the room is in darkness, and the types are illuminated by at least two brilliant electric lights shining directly upon them, and at the same time shaded from the patient's eyes (Fig. 119). The amount of illumination has a considerable effect

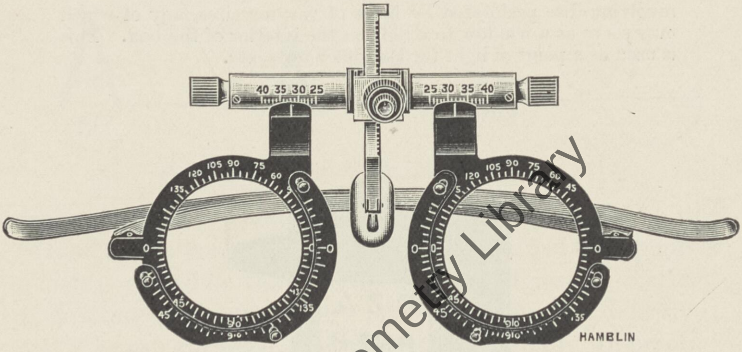


Fig. 121.—Trial Frames.

on the visual acuity. In the normal eye, below 2 foot-candles the efficiency falls very rapidly, and above this value it rises slowly and by a small amount. Consequently, if the test is to be fair, the illumination on the types should be at least 3 foot-candles.

The *trial frames* (Fig. 121) which are employed should be light and readily adaptable. They should be adjustable for each eye separately in the horizontal as well as vertical direction, so that they can be accurately fitted to an asymmetrical face. Simplicity to ensure lightness and a comfortably-fitting nose-rest are the greatest essentials, for many patients are very sensitive to the weight, and will express annoyance and dissatisfaction with the glasses which are put up for trial, complaining that they

Digitized by Illinois College of Optometry Library

make their eyes ache or give rise to a headache, when the trouble lies in the irritation caused by heavy and oppressive frames. An aluminium alloy is the best material, and a weight of more than 2 ounces is unnecessary. Each eye should be fitted with three cells: one to hold a spherical lens, one for a cylindrical lens, and one for a prism, Maddox rod, etc. The compartment for the cylinder should be susceptible of smooth and accurate rotation, so that no trouble is experienced in arriving at the correct direction of the axis. The lenses should be carried close to the eye, so that they occupy as nearly as possible the same position as the glasses will when in use. It is very advisable, also, that the compartments should be as close together as is compatible with holding the lenses, for, as will be pointed out, errors arise when any considerable distance is allowed to intervene between the constituent glasses. It will be shown also that for a similar reason the lenses should be as small as possible, the stronger ones being preferably of a lenticular form, with one surface, where practicable, plane, so that they can lie in apposition. Finally, the frames should have their side-pieces jointed, so that when the near vision is being tested by reading, the glasses can be angled so that their optical axes correspond with the downward inclination of the line of vision.

The *distance* at which the test types are placed should preferably be 6 metres; 5 metres is the shortest which should be allowed, although some use only 4 metres. If 6 metres, or at least 5, are not obtainable, the required distance should be made up by using reversed test types placed above the patient's head, and making him look at their reflection in a mirror hung on the opposite wall. In this case the light from the types travels to the mirror and then from the mirror to the patient's eyes, and thus an available room space of 3 metres can be converted optically into 6. At this distance the rays of light in the small bundle which enters the pupil suffer so little divergence that for most purposes they may be taken as parallel, that is, as coming from infinity. In actual fact the divergence at this distance is equivalent to about one-sixth of a dioptre, and in the final adjustment of glasses this divergence should be recognised and an allowance made for it.

At a distance of 3 metres a very considerable divergence comes into play, and a corresponding amount of accommodation would have to be exerted by an emmetropic eye in order to bring such rays to a focus upon the retina. This distance is therefore quite inadmissible, as it introduces fallacies. De Wecker, however, introduced a scale based on a 5-metre standard which is sometimes employed, while Edward Jackson utilises a 4-metre distance. The standard international test types, recommended by the Congress at Naples in 1909, are calculated for 5 metres; but where the requisite room space is available there is no doubt that

Digitized by Illinois College of Optometry Library

the distance proposed by Snellen of 6 metres is the more theoretically correct.

It will be found in practice that a certain type of patient—and by no means an uncommon type—persists in reading in a slow and plodding manner throughout the entire seven or eight lines of letters every time a trial glass is presented to him. It is a curious habit, peculiarly destructive to time and patience. Much time will thus be saved if the so-called cabinet types are used (Fig. 120) wherein two, or at most three lines of type are exposed at one time. Thus, for example, when a patient's vision is approximately normal, he is allowed to expatiate only on (say) the lines 6/9, 6/6 and 6/5. Such a cabinet type is controlled by a pulley affixed to a roller after the manner of a window blind. In this, as in all other forms of types, more than one set of letters should be available, for the patient readily remembers them after he has read them several times, and the later tests may therefore be fallacious.

When the patient is seated before the types under these conditions, the frames are put into position and accurately centred so that the optical centre of any lens inserted into

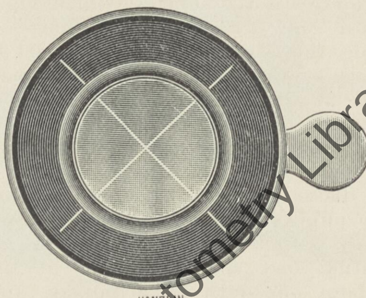


FIG. 122.—THE CENTRING LENS.

It consists of a plain glass with two cross-markings at right angles meeting at the centre.

them lies upon his visual axis. This can only be done roughly by mere inspection, and the final position should be obtained by inserting in the frames in front of each eye a glass with two cross-markings meeting in the centre (Fig. 122). The patient looks straight forwards at a light in the distance, and the surgeon notes its reflection upon the cornea. The

Digitized by Illinois College of Optometry Library

frames are then adjusted so that the cross-lines meet in the centre of the reflection. To adjust the trial frames with reference to the middle of the pupil, as is often done, is inaccurate, for this point need not necessarily be upon the visual axis.

An opaque disc is now placed in front of one eye (the left), and the patient is asked to read the lines of types with the right eye as far as he is able. The left eye is dealt with similarly; and then both eyes are tested together. It is usually found that they reinforce each other so that the binocular vision is slightly better than the uniocular. The result is usually recorded thus :—

$$\left.\begin{array}{l}\text{V.R.} = 6/6\text{, or whatever the case may be.}\\ \text{V.L.} = 6/6\text{, or whatever the case may be.}\end{array}\right\} = 6/5$$

If he cannot read the largest letter he is asked to walk towards the types, and at a certain distance he may be able to see the largest. Having thus made sure that he understands exactly where to look and what to look for, he should then be moved back a little, and the longest distance is determined at which the top letter is seen. This should be recorded in the same manner. For example, if he sees the top letter at a distance of 2 metres, then V. = 2/60. If this is found to be impossible, the surgeon holds out the fingers of his hand against a dark background (such as his coat) and asks him to count them. The vision is then recorded as at the farthest point at which the fingers are distinguishable, thus : V. = C.F. (counts fingers) at 1 metre. If this is not possible, the surgeon then moves his hand in front of the patient's eye against a light, such as the window : vision of this meagre degree is recorded as : V. = H.M. (hand movements). Even this may be beyond the patient's power, in which case the room is darkened, and a light is thrown into his eye reflected by the mirror of the ophthalmoscope : if he can recognise the presence of the light and tell when it is thrown into his eye and when it is not, the vision is recorded as : V. = P.L.

Digitized by Illinois College of Optometry Library

(perception of light). If, on the contrary, no light is recognised, the vision is recorded as : V. = no P.L. Where bare perception of light exists the light is thrown into his eye from different directions, and he is asked to point to the place from which he imagines it is coming, and in this way an indication is obtained of any area of the retina which is

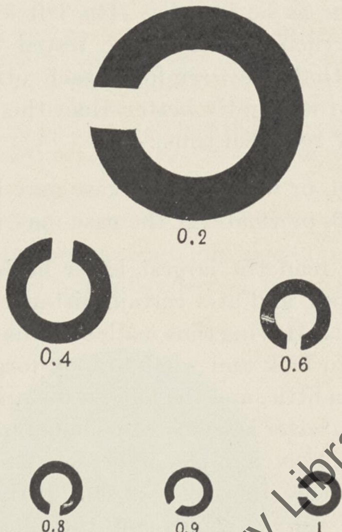


Fig. 123.—Landolt's Broken Ring Test Types.

totally blind : this faculty is spoken of as *projection* and a note is made of the extent to which it is good or bad.

The ordinary test as thus undertaken is dependent entirely upon the patient's co-operation, and in this way fails in the case of malingerers, illiterates, or young children. Illiterates may be tested by *Landolt's broken ring test* (Fig. 123). This test, which was recommended by the International Congress in 1909, has the advantage that it is applicable to persons of any nationality, while it also does away with the assistance in reading which a knowledge of the forms of the letters of the alphabet give to those who know them. The rings are

Digitized by Illinois College of Optometry Library

constructed on the same basis as regards size and visual angle as the letters of Snellen's types, and the patient is instructed to indicate by a motion of the hand at which point each one is broken.

In children who do not yet know their letters, familiar figures of varying sizes, such as a cow, a doll, etc., may be used, and from the child's description of these a very good, although perhaps not a scientifically accurate knowledge of the visual acuity is gained. In still younger children, such as may require to be tested for amblyopia in squint, Worth's *ivory ball test* may be employed. The child is allowed to handle the balls with both eyes open. One eye is then tied up, and the balls are thrown on the floor at a distance of six or seven yards. They are thrown with a slight spin so that they " break " on touching the carpet, and thus change their direction. There are five balls of graded sizes, varying in diameter from $\frac{1}{2}$ to $1\frac{1}{2}$ inches. They are thrown one by one, beginning with the largest, and the child is encouraged to run after them. In this way a rough estimate of the visual acuity can be made from the size of the smallest ball which the child can see.

Subjective Examination of the Refraction.—At this stage a rough subjective examination of the refraction is frequently made by a process of trial and error with lenses. As a general rule this procedure is redundant. Certainly where no cycloplegic is used it is unnecessary, and can be performed much more rapidly and efficiently after retinoscopy. Where a cycloplegic is used, however, especially in cases of hypermetropia, it may save the unfortunate necessity of a post-cycloplegic test. In all cases, however, a considerable amount of information can be obtained from it.

For the purposes of this examination, patients suffering from refractive errors may be divided into two classes :

1. *The patient is able to read* 6/6.—In this case the patient is either emmetropic (or approximately so) or hypermetropic. A + 1 D sphere is now placed in the trial frame in front

Digitized by Illinois College of Optometry Library

of the eye which is being tested, when one of two things may happen.

(*a*) The vision becomes blurred, in which case the patient is emmetropic, or approximately so ;

(*b*) The vision is unimpaired, or possibly improved, in which case the patient is hypermetropic, and he has been making use of his accommodation in order to see 6/6. In this case convex lenses of gradually increasing power are placed in front of the eye until a definite blurring occurs : this point, when the strongest possible lens is employed and the 6/6 line is still clearly visible, is a measure of the manifest hypermetropia. Most of these patients, especially when they are young, have considerable difficulty in relaxing their accommodation, and as soon as a convex lens is placed before the eye some blurring may be apparent. More accurate results are therefore frequently obtained by adopting the "fogging method" whereby a strong lens is put up at the commencement, and its strength is gradually diminished by adding to it concave lenses of increasing power until 6/6 is obtained ; in this way, by first of all rendering the object definitely blurred, the stimulus to maintain the accommodation is largely lost. Each eye should be tested in turn, and then the two together, when, as has already been pointed out, a small addition of + 0·25 or + 0·5 D can often be made. From this is deducted 0·12 D or 0·25 D to allow for the slight divergence of rays of light coming from a point at 6 metres, and the true manifest hypermetropia is then obtained.

2. *If the patient cannot read the* 6/6 *line*, he may be subjected to the pin-hole test ; if this improves his vision, the error is in the refractive system of this eye, and he is suffering from a degree of hypermetropia which he cannot compensate, from myopia, or from astigmatism.

A convex lens (starting at + 1·0 D) is placed before the eye : if this improves the vision, he is hypermetropic, and his manifest hypermetropia is found as before by determining

Digitized by Illinois College of Optometry Library

J. 1 (Sn. 0.5). **50 cm.**

As she spoke, Moses came slowly on foot, and sweating under the deal box which he had strapt round his shoulders like a pedlar "Welcome, welcome, Moses! well, my boy, what have you brought us from the fair?"—"I have brought you myself" cried Moses, with a sly look, and resting the box on the dresser "Ay, Moses," cried my wife, "that we

J. 2 (Sn. 0.6). **60 cm.**

five shillings and twopence is no bad day's work. Come, let us have it then."—"I have brought back no money," cried Moses again. "I have laid it all out in a bargain, and here it is," pulling out a bundle from his breast. "here they are; a gross of green spectacles, with silver rims and

J. 4 (Sn. 0.8). **80 cm.**

mother," cried the boy, "why won't you listen to reason? I had them a dead bargain, or I should not have brought them. The silver rims alone will sell for double the money"—"A fig for the silver rims," cried my wife, in a passion. "I dare

J. 6 (Sn. 1). **1 m.**

the rims, for they are not worth sixpence; for I perceive they are only copper varnished over."—"What!" cried my wife, "not silver! the rims not silver?"—"No," cried I, "no more silver

J. 8 (Sn. 1.25). **1.25 m.**

with copper rims and shagreen cases? A murrain take such trumpery! The blockhead has been imposed upon, and should have known his company better."—"There,

J. 10 (Sn. 1.5). **1.5 m.**

the idiot!" returned she, "to bring me such stuff: if I had them I would throw them in the fire."—"There again you are wrong, my dear," cried I,

J. 12 (Sn. 1.75). **1.75 m.**

By this time the unfortunate Moses was undeceived. He now saw that he had

J. 14 (Sn. 2.25). **2.25 m**

asked the circumstances of his deception. He sold the horse, it

FIG. 124.—JAEGER'S TEST TYPES FOR NEAR VISION.

Digitized by Illinois College of Optometry Library

the strongest convex lens with which 6/6 vision can be attained. If this does not improve the vision, the patient is either myopic or astigmatic. A concave lens is then presented, and if this *materially* improves the vision, he is myopic. There is very little use in determining the amount of myopia in this way in the smaller degrees of error, since if a concave lens is presented to an emmetrope, he will counteract its action by an effort of his accommodation and still retain standard vision. To get accurate results, therefore, by this method, a cycloplegic should be used to paralyse the accommodation. In the higher degrees of myopia, however, it is useful to discover what strength of sphere the patient will comfortably tolerate, especially if a mydriatic is to be used subsequently. In this case the weakest concave lens with which the patient can see 6/6 gives a measure of the amount of myopia. If neither convex nor concave lenses materially improve vision, the case is probably one of astigmatism. It is possible to get an approximate idea of the error by a similar process with the use of an astigmatic fan, or by the trial of lenses with a stenopæic slit in two meridians at right angles, but this can serve no useful purpose until an exact estimation of the error with its axis has been made by retinoscopy.

The Testing of Near Vision

When the distant vision has been tested, the visual acuity at reading distance is investigated; for this, test types are also employed. Snellen has constructed a set of letters of graded sizes and thicknesses on the same principles as his distant types, and this is the most scientifically accurate test to use. As a rule, however, owing to the unusual configuration of letters of this construction, Jaeger's types are more popular (Fig. 124). These are simply the ordinary printer's founts of type of varying sizes (nonpareil, minion, etc.), and they are sufficiently accurate for all practical purposes.

Digitized by Illinois College of Optometry Library

The patient remains seated in the chair, and with a good light thrown over the left shoulder, he is given the card with the test types to hold and asked to read them. The position at which he holds them will frequently suggest useful information. If he holds them far away, and if he moves them still further out when he is struggling to make out a word that he can see only with difficulty, he is hypermetropic, or, if he is beyond middle age, he is presbyopic. If, however, he holds them more closely than the ordinary distance of about 25 to 30 cm., he is probably myopic. The near vision is recorded as the smallest type which he can comfortably read with a note of the approximate distance at which the card is held: thus—N.V. = J. 1. at 30 cm.

Digitized by Illinois College of Optometry Library

CHAPTER XX

OPHTHALMOSCOPIC EXAMINATION

When the functional testing of the visual acuity has been completed, the room is darkened, and after the anterior parts of the eye have been examined again with intense focal

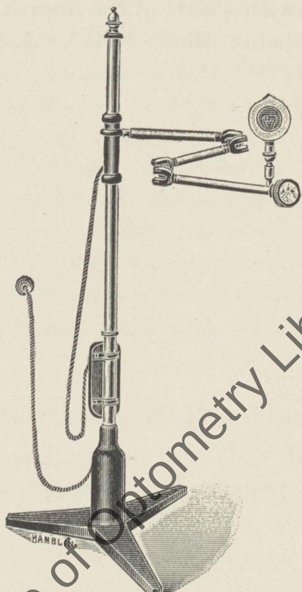


Fig. 125.—The Ophthalmic Lamp.

illumination, the ophthalmoscopic examination is undertaken. This is essential in order to detect the presence of any opacities in the media and to investigate the state of the fundus, and it also incidentally provides useful information as to the nature of the refraction. This information is by no

Digitized by Illinois College of Optometry Library

means exact and is not to be relied upon as a final estimation. It is noted briefly here partly because of its general interest, and partly because, occupying a negligible amount of time in the course of the general routine examination, it imposes little additional labour upon the refractionist.

It is not absolutely essential that the room should be perfectly dark in conducting these examinations, but it should be as dark as it is possible to make it. This is important for three reasons. In the first place, the pupils dilate in the dark, and their dilatation greatly facilitates retinoscopy when no mydriatic is employed. Again, in the dark the accommodation is more readily relaxed. An adequate relaxation of accommodation is only possible with

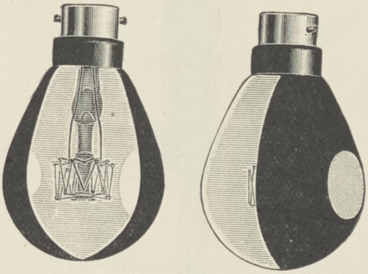


Fig. 126.—The Lister Electric Light Bulb.

the average patient when the examination is conducted in a large room, and for this reason a small dark room should never be used for retinoscopy in the absence of a cycloplegic. This point will be mentioned later. Lastly, when the room is darkened the interior of the eye appears more distinctly illuminated and the shadows in retinoscopy are more clearly defined in contrast to their surroundings.

The light employed should be brilliant and must burn evenly. An electric light is the most generally applicable, but in its absence the most steady and uniform flame is given by an Argand gas burner or a duplex wick petroleum lamp. The light should preferably be mounted upon a movable jointed arm (Fig. 125), so that it can be raised or lowered or moved from side to side. The value of the illumination is very much increased if the light is limited to a narrow beam of parallel (or approximately parallel) rays, leaving the rest of the room in shadow. The ideal source of illumination, therefore, especially for retinoscopy, is a point-o'-light, enclosed in an opaque casing with a window on one side. When an electric bulb is used, the type suggested by Lister is most useful (Fig. 126). Here the whole of the bulb is blackened

Digitized by Illinois College of Optometry Library

except the windows required on the sides, and the intensity of the beam is increased by silvering the inner surface, thus making it act as a reflecting mirror. An ordinary lamp is greatly improved by enclosing it in a chimney, on the side of which is a circular aperture placed immediately opposite the brightest part of the filament or flame, and this can be guarded by an iris diaphragm so that the illumination can be regulated. A convenient aperture is 10 or 15 mm. in diameter.

The best type of ophthalmoscope for general purposes is some modification of Morton's (Fig. 127). It should be provided with two large mirrors for indirect ophthalmoscopy, one plane and one concave with a focal length of 25 cm., each pierced with a central

Fig. 127.—The Morton Ophthalmoscope.

hole of 3 or 4 mm. diameter. There should also be two small mirrors inclined at an angle of 45 degrees to the plane of the ophthalmoscope for examination by the direct method, one plane and one concave with a focal length of 20 cm., each being pierced by a central hole of 2 mm. diameter. A battery of lenses from about + 30 to − 30 D should also be attached. For the indirect method a condensing lens is also required; this is preferably mounted on a handle, and for ordinary purposes its strength should be about + 13 D, that is, its focal length should be 7·5 cm. It will be shown later that the image in myopia is small, and in the higher degrees of error a weaker lens of + 9 or + 10 D will give a more enlarged image. Conversely, in high degrees of hypermetropia, where the image is large, a stronger lens of about + 16 D will give a smaller, but more distinct picture.

Digitized by Illinois College of Optometry Library

Preliminary Examination with the Plane Mirror.—In the first part of the routine examination the plane mirror alone is employed. The patient should remain seated with the source of illumination above his head, and the surgeon faces him directly, at a distance of 1 metre. The light is reflected into the eye by the plane mirror and the surgeon, while he looks through the central hole, sees the pupil in the normal eye lit up by a red glow.

This is the red reflex of the fundus. In ordinary circumstances the pupil appears black, because little light can enter

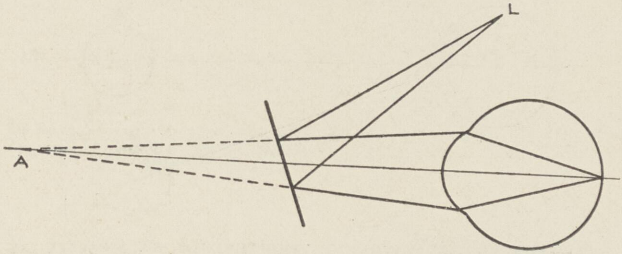


FIG. 128.—THE PATH OF THE RAYS OF LIGHT IN OPHTHALMOSCOPY WITH THE PLANE MIRROR.

L is the source of light. The rays entering the eye after reflection from the mirror act as if they came from A.

it through the small aperture of the iris, and since the greater part of this is absorbed by the pigment of the eye, a still less amount is available which can be reflected back into the eye of the observer. Moreover such light as is reflected back emerges as a narrow bundle of rays which can only be appreciated if the observer is directly in their path. Since the red background of the fundus can only be seen when light travels from it into the observer's eye, it is evident that this will rarely happen in the ordinary course of events. The red glow is seen easily in the eye of the albino, because a large quantity of light can enter his eye through his sclerotic and iris, which are rendered semi-transparent in the absence of pigment; it is also seen in the eyes of those animals,

Digitized by Illinois College of Optometry Library

such as carnivora, which are provided with a tapetum, a structure at the posterior pole of the retina which is highly polished and thus acts as a reflecting mirror.

In the favourable circumstances which we have arranged, however, the red reflex is readily seen in the normal eye, for an intense beam is thrown into it through the pupil, and the observer's eye is placed directly in the path of the emergent rays. A diagram of the path of the rays is seen in Fig. 128.

An examination of the transparency of the media should first be made. Any opacities will obstruct the light travelling from

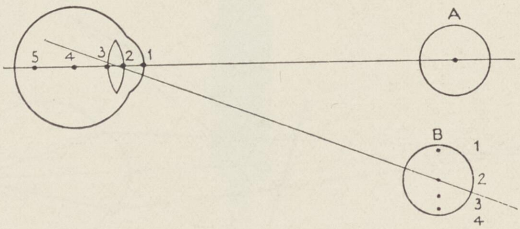


FIG. 129.—THE DETERMINATION OF THE SITE OF AN OPACITY BY THE METHOD OF PARALLAX.

The opacities in the eye are situated thus: 1, on the cornea; 2, on the anterior surface of the lens; 3, on the posterior surface of the lens; 4, in the middle of the vitreous; 5, in the posterior region of the vitreous. When looked at directly, each of these appears as a central opacity as in A. When the mirror is turned downwards, or the eye looks up, they are orientated with reference to the line passing through the plane of the pupil, and appear as in B. 1 appears to move upwards; 2 remains centrally; 3 moves downwards; 4 moves to the extreme lower margin of the pupil; and 5 disappears from view.

the fundus of the patient to the observer's eye and will therefore appear black. The position of the opacities can be made out by the method of parallax. The picture of the fundus is referred optically to the pupillary plane, and if the eye is moved in a vertical direction an opacity at this level, that is, near the anterior surface of the lens, will remain still; one in front of this plane, that is, in the cornea, will appear to travel in the same direction as the eye, while one behind this, that is, in the posterior lens or vitreous, will appear to move in the opposite direction, the amplitude of apparent movement being an indication of the distance of the opacity from the pupillary plane. The phenomenon is illustrated in Fig. 129. The reflex should also be uniform, and any variation

Digitized by Illinois College of Optometry Library

in its character, whereby a portion appears less red, or even grey, should suggest a detached retina. These phenomena can be studied in more detail if the surgeon approaches the patient and verifies his observations at a comfortable distance for near vision, about 9 or 10 cm. away.

Some indication of the nature of the refraction can be deduced from the appearances seen at this stage. In the

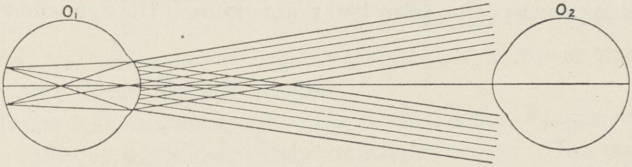


Fig. 130.—The Emergent Rays of Light from the Fundus of the Emmetropic Eye.

O_1 is the patient; O_2 the observer. The light leaves the eye in parallel bundles of rays, only one of which can be received by the eye of the observer seated at 1 metre distance.

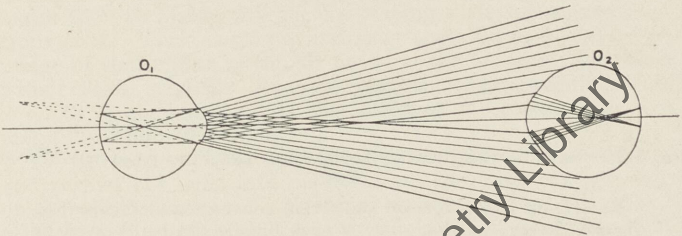


Fig. 131.—Path of Rays of Light from the Fundus of a Hypermetropic Eye.

The light from two points on the retina leaves as two diverging bundles of rays, some of the peripheral rays of each of which can be received by the observer's eye. He therefore sees an image of the fundus.

emmetropic eye, or in the eye with a small refractive error, the reflex is uniform, but in high degrees of ametropia some details of the fundus can be distinguished.

The explanation of this is simple, and is best represented pictorially. In the emmetropic eye the rays issuing from any point on the retina are parallel, and since the bundles of rays from two points on the retina diverge after leaving the

Digitized by Illinois College of Optometry Library

eye, the observer situated at 1 metre cannot receive portions of both bundles simultaneously through his pupil (Fig. 130). He cannot therefore see two spots on the retina but can only focus one at a time, and thus sees only a general illumination. In the hypermetropic eye, however, the emerging rays are divergent, and the two bundles of rays from two points on the retina will form two divergent bundles (Fig. 131). These will appear to come from two points behind the eye where an

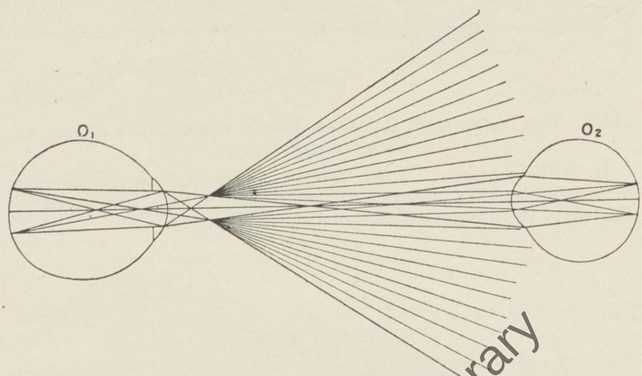


Fig. 132.—Path of the Rays of Light from the Fundus of the Myopic Eye.

Rays from two points on the retina converge and then subsequently diverge, so that some of each bundle can be received by the observer's eye. He therefore sees an image of the fundus.

imaginary erect image is formed. Since each bundle diverges, some of the peripheral rays of each will be received by the observer's pupil, so that he will obtain a clear image of each point and thus see the virtual image behind the patient's eye. In myopia, on the other hand, the rays coming from the two points (Fig. 132) will be convergent and will form a real inverted image in front of the eye. Continuing from this image the rays will diverge in two bundles, the peripheral parts of which will enter the observer's pupil. He will thus see a small inverted image of the fundus. If the observer now

Digitized by Illinois College of Optometry Library

moves his head from side to side, the erect image will appear to move in the same direction, and the inverted image in the opposite one.

It therefore follows that in the preliminary examination with the plane mirror, if the fundus reflex is seen as a uniform red glow the eye is emmetropic or approximately so; but if any details of the retinal structure are seen a considerable degree of ametropia exists. If the picture thus presented appears to move in the same direction as the observer's head, the refraction is hypermetropic; if it moves in the opposite direction, it is myopic.

Indirect Ophthalmoscopy.—The fundus is now examined by the indirect method with the ophthalmoscope. Here again the primary object of the examination is to eliminate disease of the retina or choroid, but at the same time several phenomena depending on the refraction can be noted.

The principle of the indirect method of ophthalmoscopy is to make the eye highly myopic by placing a strong convex lens in front of it. This, as we have already seen, forms a real inverted image of the fundus in the air between the lens and the observer which can be studied. Such an image is always magnified; with a + 13 D condensing lens the retina of the emmetropic eye is magnified about five times.

The surgeon remains seated before the patient 1 metre away, and throws the light into his eye from the large concave mirror of the ophthalmoscope. Keeping his eye on the red reflex, he interposes the condensing lens in the path of the beam of light close up to the patient's eye, and slowly moves the lens from the eye towards himself until the image of the retina is seen clearly. In order to bring the optic disc into view when the patient's left eye is being examined, he is asked to look at the surgeon's left ear, and when his right eye is being examined a convenient point of fixation is the little finger of the surgeon's right hand, which is extended as he holds the ophthalmoscope up to his right eye.

For the beginner this requires practice, and some difficulties may be encountered. One of these is the formation of reflexes by the surface of the cornea and the two surfaces of the lens which act as mirrors. By tilting the condensing lens slightly, the latter two are separated, and the observer can look between them. The first can also be got rid of by holding the condensing lens at a distance equal to its focal length from the anterior focus of the eye, that is, about 9 cm. away. In this case

Digitized by Illinois College of Optometry Library

the tilting of the lens moves the corneal reflex and the image of the fundus in opposite directions, so that the view is unimpaired. The tilting should not be overdone, as otherwise a false astigmatic effect will be produced.

Finally, it is to be remembered that the observer must remain a metre away from the eye he is examining, for, although he seems to be looking at the pupil, he is in reality studying an image in the air between the condensing lens and himself; consequently, if he approaches too closely it will become indistinct. If he finds it difficult to maintain a distance suitable for his accommodation, he will be aided if he puts up a + 1 or + 2 D lens behind the mirror in the ophthalmoscope.

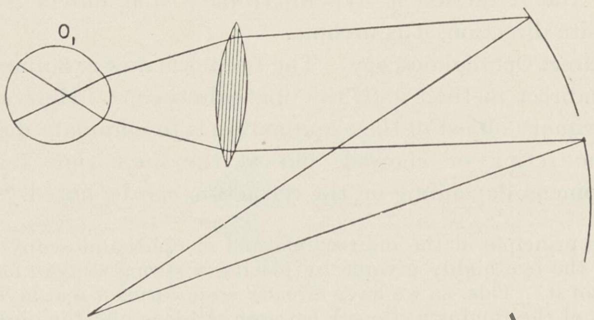


Fig. 133.—The Path of the Rays of Light to the Eye in the Indirect Method of Ophthalmoscopy with the Concave Mirror.

The path of the rays of light to the eye is seen in Fig. 133. In the emmetropic eye rays coming from the fundus are parallel, and are therefore brought to a focus by the condensing lens. It will be seen from Fig. 134 that an inverted image of the retina is therefore formed in the air at the principal focus of the lens, between it and the observer's eye. In hypermetropia the emerging rays will diverge, and they will thus appear to come from an imaginary enlarged upright image situated behind the eye (Fig. 135). The condensing lens therefore uses this as an object, and forms an inverted image of it. Since the rays are divergent this final image will be situated in front of its principal focus. In the myopic eye, on the other hand, the rays coming from the fundus are convergent, and therefore an inverted image

Digitized by Illinois College of Optometry Library

is formed in front of the eye (Fig. 136). The condensing lens then forms a second smaller image of this at a point

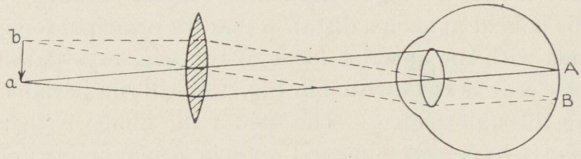


FIG. 134.—PATH OF THE LIGHT FROM THE EYE IN THE INDIRECT METHOD OF OPHTHALMOSCOPY IN EMMETROPIA.

AB, the illuminated area on the retina, gives an image, *ab*, in the air on the side of the condensing lens farthest from the eye.

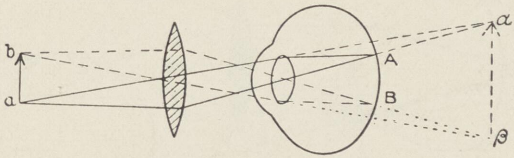


FIG. 135.—PATH OF THE RAYS OF LIGHT FROM THE EYE IN INDIRECT OPHTHALMOSCOPY IN HYPERMETROPIA.

AB, the illuminated area on the retina gives an imaginary image $\alpha\beta$ behind the eye. This is focused in a final image at *ab* by the condensing lens.

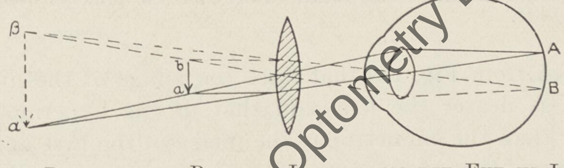


FIG. 136.—PATH OF THE RAYS OF LIGHT FROM THE EYE IN INDIRECT OPHTHALMOSCOPY IN THE MYOPIC EYE.

AB, the illuminated area on the retina, forms an inverted aerial image in front of the eye at $\alpha\beta$. The condensing lens gives a final image (*ab*) situated within its own focal length.

within its focal length. The relative position of these images will be evident from Fig. 137.

It follows that in the emmetropic eye no matter what the

Digitized by Illinois College of Optometry Library

position of the lens may be, the size of the image always remains the same, and will be situated at its principal focus, because the rays issuing from such an eye are parallel. When the lens is held at such a distance that its principal focus corresponds with the anterior focus of the eye, rays parallel to the optic axis as represented in Fig. 138 will run parallel after passing through the lens. The size of the image is therefore the same in hypermetropia and myopia as in emmetropia. If, however, the principal focus is nearer to the eye than this, such rays will leave the lens in a divergent direction. In this case

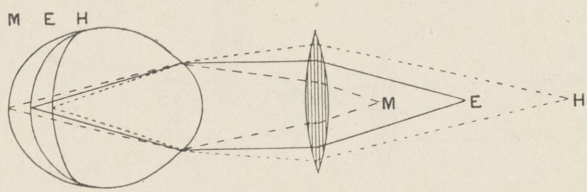


Fig. 137.—The Relative Positions of the Image in Indirect Ophthalmoscopy in Emmetropia, Hypermetropia, and Myopia.

The lens is situated at its own focal distance from the cornea. In emmetropia the emergent rays are parallel and therefore cross at the principal focus of the lens (E). In myopia the emergent rays are convergent, and cross nearer to the lens than its principal focus, *i.e.*, at M. In hypermetropia the emergent rays are divergent, and therefore cross farther away than the principal focus, *i.e.*, at H.

it is seen from Fig. 139 that since the image of the myopic fundus is nearer the lens and that of the hypermetropic farther than the emmetropic, the image of the first must be smaller and that of the second larger. Conversely, when the principal focus of the lens is farther from the eye than the anterior principal focus, these rays converge after leaving the lens, and the opposite relation will be produced (Fig. 140).

Consequently an idea of the refraction can be gathered from the size of the image as seen by the indirect method. When the condensing lens is held nearer to the eye than 9 cm., as is usually the case (that is, when its principal focus

Digitized by Illinois College of Optometry Library

is nearer to the eye than the anterior focus), the image of the disc in myopia will be smaller than usual, and in hyper-

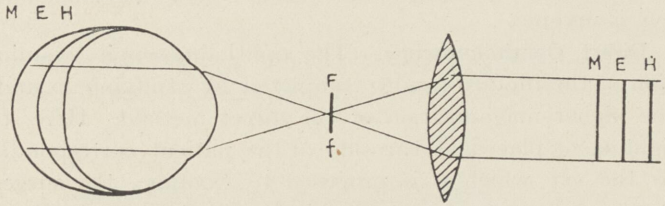


FIG. 138.—The size of the image in different refractive states when the condensing lens is held at such a distance that its principal focus (f) corresponds with the anterior focus of the eye (F). The size of the image is the same in hypermetropia and myopia as in emmetropia.

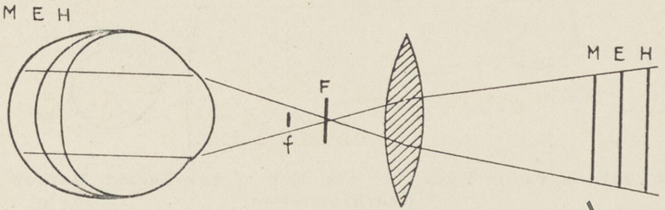


FIG. 139.—When the principal focus of the condensing lens (f) is nearer to the eye than the anterior focus of the latter (F), the image of the myopic eye is smaller and that of the hypermetropic eye larger than that of the emmetropic eye.

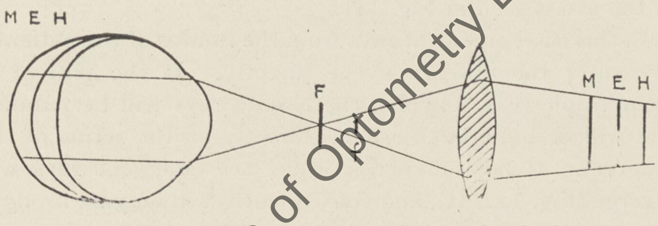


FIG. 140.—When the principal focus of the lens (f) is farther away than the anterior focus of the eye (F), the image of the myopic eye is larger and that of the hypermetropic eye smaller than that of the emmetropic eye.

metropia it will be larger. In astigmatism it will be oval and will change its shape as the condensing lens is moved (see Fig. 143). When we therefore place the lens close up to

Digitized by Illinois College of Optometry Library

the eye and slowly bring it farther away, if the image of the disc does not alter in size, the eye is emmetropic ; if it decreases, the eye is hypermetropic ; and if it increases, the eye is myopic.

Direct Ophthalmoscopy.—The ophthalmoscopic examination of the fundus is now completed by studying it under the higher magnification of the direct method. Here, the light being placed at the side of the patient corresponding to the eye which it is proposed to examine, the surgeon approaches quite close up to him, and using the small concave mirror of the ophthalmoscope angled in the appropriate direction and held as closely to the eye as is convenient, he

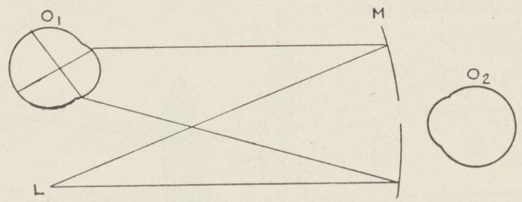


Fig. 141.—Path of Rays into the Eye in the Direct Method of Ophthalmoscopy.

M, the mirror of the ophthalmoscope ; O_1, the patient's eye ; O_2, the observer's eye ; L, the source of light.

reflects the light into the eye. The path of the rays of light to the eye is seen in Fig. 141.

In this case, emergent rays from the fundus of the patient's eye enter the observer's eye directly. If the patient is emmetropic (Fig. 142, E), the issuing rays will be parallel, and will be brought to a focus directly on the retina of the observer. If he is hypermetropic, the emergent rays will diverge (Fig. 142, H), and consequently will only be brought to a focus on the observer's retina if he accommodates, or by the help of a convex lens. If he is myopic, they are convergent (Fig. 142, M), and must be made more divergent by the interposition of a concave lens if a similar focus is to be formed. In emmetropia, therefore, the image of the retina is seen clearly without any lens in the ophthalmo-

Digitized by Illinois College of Optometry Library

scope ; in ametropia, in order that the image be clearly seen, a lens corresponding to the refractive error must be used, and the strength of this lens is thus a measure of the refraction.

If this is to be correctly estimated, however, several precautions must be observed. Firstly, the accommodation of both the patient and the observer must be thoroughly relaxed, and

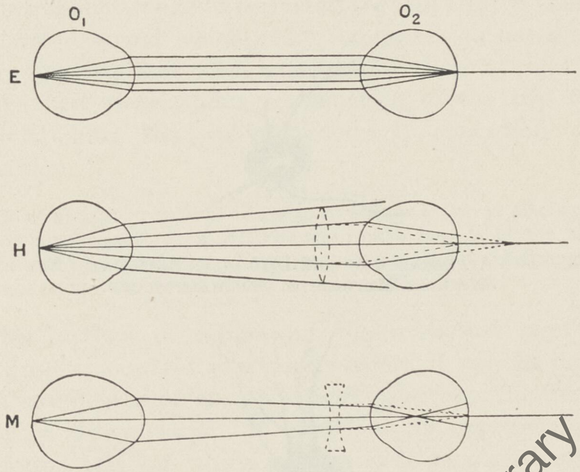


Fig. 142.—Path of Rays from the Eye in the Direct Method of Ophthalmoscopy.

In emmetropia (E) the emergent rays are parallel and therefore brought to a focus on the retina of the observer's eye (O_2) if he is emmetropic (or corrected) and his accommodation is at rest. In hypermetropia (H) the emergent rays are divergent, and can only be brought to a focus on the retina of O_2 by means of accommodation or a convex lens. In myopia (M) the emergent rays are convergent, and if they are to meet on the retina of O_2, they must be diverged into parallelism by a concave lens.

this is not always an easy matter unless a cycloplegic is used for the patient, and the surgeon is an adept at relaxing his accommodation at will. Any refractive error which the surgeon may have must also be corrected ; or, failing this, his error must be known, and deducted from the result obtained.

Ideally, the refraction at the macula should be estimated,

Digitized by Illinois College of Optometry Library

but when the light is thrown upon this region, the pupil contracts, and the reflexes obscure the vision. The region of the optic disc is therefore usually chosen, since here the sensitivity of the retina is less, and in this region there are large blood vessels which form useful points upon which to focus.

When the accommodation of both parties is relaxed,

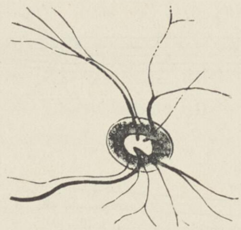


Fig. 143.—The Appearance of the Disc in an Astigmatic Eye by the Indirect Method of Ophthalmoscopy.

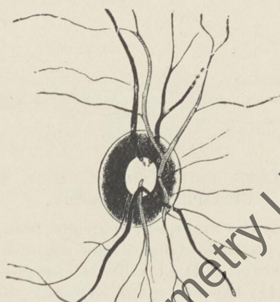


Fig. 144.—The Appearance of the Disc in the same Astigmatic Eye as Fig. 143 by the Direct Method of Ophthalmoscopy. (Nettleship.)

and the refractive error of the surgeon is corrected, and when the mirror of the ophthalmoscope is held at the anterior focus of the eye (15.7 mm. in front of the cornea), if the region of the disc is clearly seen in all directions, the eye is emmetropic. If it is not, gradually increasing convex glasses are turned in front of the observer's eye, and the strongest glass with which a clear image is obtained gives a measure of the hypermetropia. If, however, convex glasses make the blur-

Digitized by Illinois College of Optometry Library

ring more marked, concave glasses are tried, and the weakest of these with which the fundus can be clearly seen gives a measure of the amount of myopia. If astigmatism exists, the lines of the blood vessels will be unequally blurred in different directions, and when spherical lenses are presented in the ophthalmoscope, only those lines which are perpendicular to the meridian which is corrected are seen clearly. The glass is therefore found which make the vessels in one meridian clear, and then that other which makes those at right angles to the first clear, and a combination of the two can be resolved into the sphero-cylindrical correction of the refraction.

The oval appearance of the disc in astigmatism is also apparent by the direct method, and since the image here is direct, while in the indirect method it was inverted, the long axis of the oval will be seen to run in the opposite direction (Fig. 144).

This method of estimating the refraction requires an immense amount of experience before it can be practised with any degree of accuracy, and even then, the margin of error is always large. It is not to be recommended as a routine test on which reliance is to be placed, although it may be useful as an emergency measure when for one reason or another (for example, with a bed-ridden patient where apparatus is not available) a more efficient method is impracticable.

Digitized by Illinois College of Optometry Library

CHAPTER XXI

RETINOSCOPY

When the ophthalmoscopic examination of the patient has been completed and the presence of disease has been excluded, the refraction should be estimated objectively by retinoscopy. This is by far the most useful and deservedly popular method, and when it is performed by an expert under adequate optical conditions, reliable results to an accuracy of 0·25 D can be readily obtained.

These optical conditions are most important. As was indicated in the ophthalmoscopic examination, the room should be as dark as possible. It should also be large. It is impossible for the majority of patients to relax their accommodation if this is not the case. Where a cycloplegic is not used, it is impossible in most cases to refract the macular region, since when the beam of light falls here, the pupil contracts, and the view is obscured by reflexes. A slightly eccentric position is therefore chosen, and the patient is instructed to look past the surgeon's head on the side opposite to that which corresponds to the eye under examination. Obviously the less eccentric the gaze the better, and, essentially, the accommodation must be relaxed. The best way to ensure these two objects is to have two small red spot-lights fixed to the opposite wall at least 6 metres away, at which the patient can look steadily in the appropriate direction ; or, alternatively, one light exactly opposite can be employed, and the surgeon can orientate himself slightly to one side or other when the opposite eye is being refracted.

The source of light, as pointed out already, should be small, bright, and enclosed, leaving only an approximately parallel beam ; a point-o'-light is ideal, failing which an enclosed electric light should be used, the aperture in the opaque hood being 10 to 15 mm. in diameter. A plane mirror should be employed, as it gives more accurate results than a concave one, and the central opening should be at least 4 mm. in diameter, so that an abundance of light can enter the observer's eye. With a plane mirror the advantages of a hole of this size are counterbalanced by the appearance of a circular dark patch in the centre of the reflection

Digitized by Illinois College of Optometry Library

corresponding to the hole, which reduces the illumination in the pupillary area and confuses the retinoscopy. This difficulty is overcome by using the Lister mirror. This mirror is very slightly concave, so that its focal length is greater than the distance between the surgeon and the patient, that is, at least 150 cm. Consequently, as will be more clearly understood from the subsequent explanation, for the purposes of retinoscopy it acts in the same manner as a plane mirror. At the same time, the rays are made to converge slightly upon the pupil, increasing the illumina-

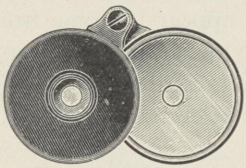


Fig. 145.—The Retinoscopy Mirror.

On one side is a plane mirror, on the other a concave mirror.

tion there and eliminating the shadow of the central hole. Since its action is identical with that of a plane mirror, it will be referred to as such in the following pages. The hole should be pierced, and not be formed by a defect in the silvering of an imperforate mirror, as the glass reflects an appreciable fraction of the light which should enter the eye. If it is pierced, annoying reflexes may be formed at the edges, but these are avoided if the edges of the hole are blackened and are made to widen out posteriorly so that it is narrowest at the mirror end. For ease of manipulation a small portable pocket mirror (Fig. 145) is preferable to using the plane mirror of the ophthalmoscope.

The Theory of Retinoscopy

If a point of light is placed in front of the eye, the rays entering the pupil will be refracted so that they are brought to a focus, or a partial focus, upon the retina, thus illuminating a circular area of the fundus. If a point of light is represented by O in Fig. 146, whatever the refractive condition of the eye, a luminous area will be formed at X. If we now imagine that O moves upwards to O″, the centre of the image must still lie along the line which connects the object (O″) to the nodal point (N), and therefore the image

Digitized by Illinois College of Optometry Library

on the retina must be displaced downwards to X′. Accordingly, if the object is moved, the retinal image always moves in the opposite direction.

Let us now consider the rays of light emerging from the eye, in which case the illuminated area acts as the source. In the hypermetropic eye these rays will be divergent, and they will thus appear to come from an imaginary focus situated behind the eye. If X in Fig. 147 is the illuminated area, the light will appear to come from A. Now if X be moved to X′, it is evident that A will appear to move to A′ that is, when the illuminated area moves down, the circle of light will appear to move down also. In order that the

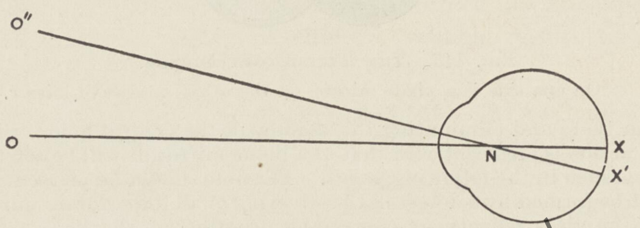


Fig. 146.—The Movement of the Retinal Image with reference to the Luminous Object.

If O is the object, and X the retinal image, when O is moved up to O″, X is moved downwards in the opposite direction to X′.

image be displaced downwards to X′, it follows from the previous figure that the object must move upwards from EE′ to DD′. The image therefore appears to move in the opposite direction to the object.

In a highly myopic eye, on the other hand, the rays of of light emerging from the illuminated area of the eye (X, Fig. 148) will be converging and will be brought to a focus at A in front of the eye. If the illuminated area is moved downwards to X′, the image will appear to be formed at A′, that is, it will have moved upwards, in the opposite direction. The movement is thus the reverse of what happened in the hypermetropic eye. To produce this downward movement of the illuminated area, we have

Digitized by Illinois College of Optometry Library

seen from Fig. 146 that the object must have been moved upwards, and consequently, owing to this double reversal, the object and the apparent image appear to move together.

It is evident that there must be a point when these two opposing movements are neutralised. We have seen from Fig. 147 that if the image appears to be formed behind the patient's head, that is, if the far point is situated behind his eye, the image moves in the opposite direction to the object.

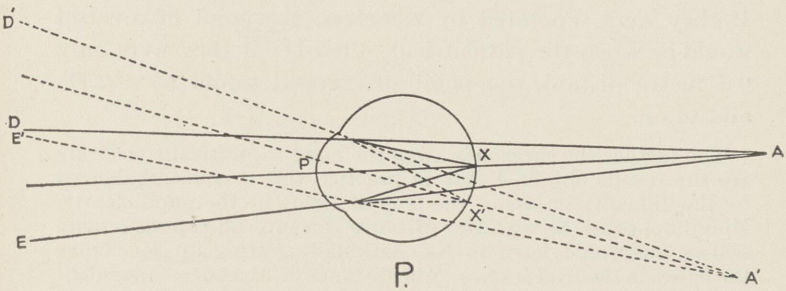


Fig. 147.—The Movement of the Retinal Image in the Hypermetropic Eye.

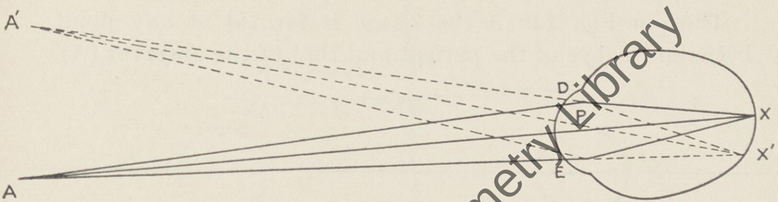


Fig. 148.—The Apparent Movement of the Retinal Image in the Highly Myopic Eye.

Conversely (Fig. 148), if the far point is situated in front, between the patient's eye and the observer's eye, the object and the image appear to move together. It will be remembered that in an emmetropic eye the far point is at infinity. Consequently, if the observer were at infinity, with a hypermetropic eye the image would appear to move in the reverse direction, and with a myopic eye the image would appear to move in the same direction. In the case of an emmetropic eye the two movements would be neutralised, and the

Digitized by Illinois College of Optometry Library

point of reversal would occur. It is not, of course, possible for the observer to be at infinity, and when an arbitrary distance is chosen, this distance takes the place of infinity for our present purpose. It therefore follows that the point of reversal occurs where the far point of the patient corresponds with the observer's eye. If the two be separated by a distance of 1 metre, the far point of the patient must be 1 metre away, and therefore he must have — 1 D of myopia. If they were separated by 2 metres, the point of reversal would be when the patient had — 0·5 D ; if they were only 0·5 metre distant, the point of reversal would be — 2 D ; and so on.

The further the surgeon is away the more theoretically accurate are the results obtained, but in practice this is counterbalanced by the difficulty in seeing the play of lights in the pupil clearly. More important, at a greater distance the surgeon cannot remain seated, but would have to be continually getting up to change the lenses in the trial frames. The distance of 1 metre is convenient because the patient can be reached, the pupil can be well seen, and the margin of error is reasonably small.

Thus in Fig. 149 if the image is formed at any point between the eye of the patient and that of the observer (A),

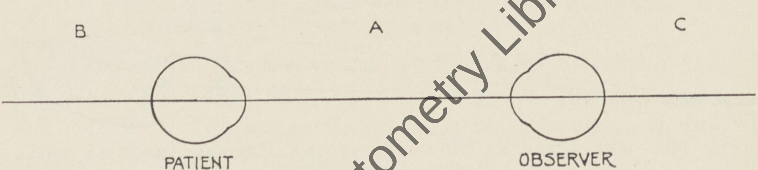


Fig. 149.—To Illustrate the Point of Neutralisation of the Shadows in Retinoscopy.

A, the region between the patient and the observer ; B, the region behind the patient ; C, the region behind the observer.

the image and the object move together ; if it falls outside of this region, either behind the patient's eye (B) or behind the observer's (C), they move in the reverse direction. If we suppose the distance apart to be 1 metre, if the myopia is greater than — 1 D, the image will be within the region A (Fig. 149) and will move with the object ; if the

Digitized by Illinois College of Optometry Library

myopia be less than — 1 D it will be referred to the region (C); if the eye is emmetropic it will be at infinity, and if it be hypermetropic it will appear to come from the region (B) —in all these cases it will move in the reverse direction to the object.

In the practice of retinoscopy the object used is the image

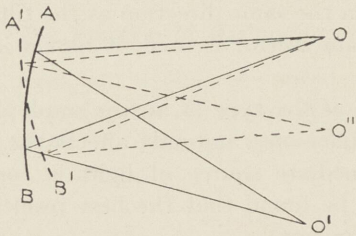


Fig. 150.—The Image of a Concave Mirror.

When the mirror is at AB, the image of O is at O′; when the mirror is tilted to A′B′, the image moves in the same direction to O″.

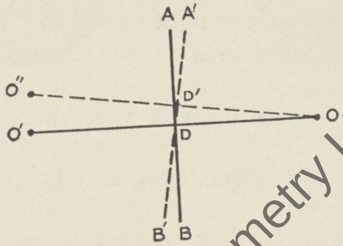


Fig. 151.—The Image of a Plane Mirror.

When the mirror is at AB, the image of O is at O′; when the mirror is tilted to A′B′, the image moves in the reverse direction and appears to come from O″.

of a source of light as formed by a mirror, and movements of the object are obtained by tilting the mirror. If a concave mirror is used, the image formed by it lies in front of the mirror, and, as is seen in Fig. 150, when the mirror is tilted upwards, the image moves upwards so that the above relations hold good. When a plane mirror is used, however, the image appears to be formed behind it. Thus if the source

Digitized by Illinois College of Optometry Library

of light is represented by O (Fig. 151) the image is formed at O′. If, now, the mirror be tilted downwards from the position AB into the position A′B′, the image will appear to have moved upwards and will lie in the position O″. When a plane mirror is tilted in any direction the image therefore moves in the opposite direction. It follows that when a concave mirror is used the illuminated area on the fundus moves in the same direction as the tilt of the mirror, and when a plane mirror is used, it moves in the opposite direction.

The question of the type of mirror employed is therefore merely a subsidiary one, and only affects the direction from which the immediate source of light is coming; but in practice it will be found that the best results are obtained from the plane mirror.

Hence under the conditions of retinoscopy with a plane mirror:

when the mirror is tilted to the right,
the immediate source of light moves to the left,
and the illuminated area of the fundus moves to the right.

Therefore in the hypermetropic eye, the image moves to the right;
in the myopic eye (higher than − 1 D) it moves to the left;
in the myopic eye of − 1 D the pupil will appear completely bright or completely dark;
and in the myopic eye of less than − 1 D, a faint shadow will move to the right.

In practice the illuminated area of the fundus is not so readily observed as the edge of the unilluminated area which borders it, for on movement this appears as an advancing or receding shadow. When, therefore, a plane mirror is used, if this shadow moves in the same direction as that in which the mirror is tilted, the eye is hypermetropic, emmetropic, or myopic to an amount less than

Digitized by Illinois College of Optometry Library

— 1 D; if no shadow is seen at all, but the pupil appears uniformly bright or dark on moving the mirror, the eye has — 1 D of myopia; if the shadow moves in the reverse direction, there is myopia of more than — 1 D.

With a concave mirror, of course, exactly the reverse movements are seen.

The Practice of Retinoscopy

The patient, then, sits facing the surgeon at a distance of 1 metre, and relaxing his accommodation, preferably by fixing a red light in the distance, directs his gaze slightly eccentrically across the direct line between them. The

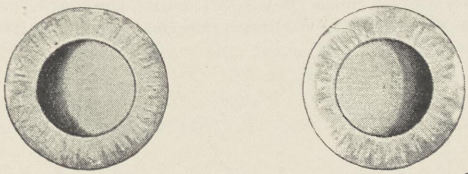


Fig. 152.—Retinoscopy Shadows.

surgeon holds the plane retinoscopy mirror up to his eye and throws the light into the patient's pupil. He then slowly tilts the mirror from one side to the other, and notes the appearance and movement of the shadow (Fig. 152).

If the patient has — 1 D of myopia, no definite shadow is seen, but the pupillary area appears entirely illuminated or entirely dark. In the lower degrees of myopia and in emmetropia, the shadow is faint and has a straight border, while in the higher degrees of ametropia, it is accentuated and dark and has a definitely curved edge. When the mirror is moved, the greater the error of refraction, the slower the movement of the shadow. This will be evident from Fig. 153. In myopia the image is formed in front of the eye at its far point, and the higher the degree of myopia, the nearer the

Digitized by Illinois College of Optometry Library

far point; on tilting the mirror, therefore, a low degree of myopia will entail a large excursion of the image (C*c*), while a high degree will only involve a small one (D*d*). Similarly, in hypermetropia where the image is formed behind the eye,

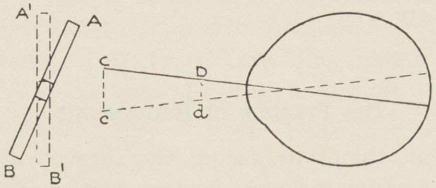


FIG. 153.—TO ILLUSTRATE THE RATE OF MOVEMENT OF THE SHADOW IN RETINOSCOPY IN THE MYOPIC EYE.

When the mirror is in the position AB, the image is at D in the highly myopic eye, and at C in the less myopic eye. When the mirror is in the position A′B′, the respective images are in the positions *d* and *c*. Since D*d* is less than C*c*, the lower the degree of myopia, the larger the excursion and the quicker the movement of the shadow.

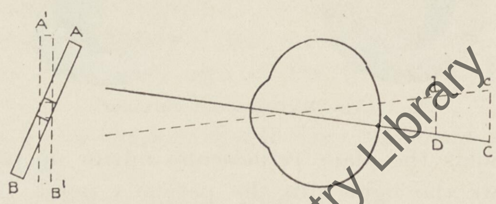


FIG. 154.—TO ILLUSTRATE THE RATE OF THE MOVEMENT OF THE SHADOW IN RETINOSCOPY IN THE HYPERMETROPIC EYE.

When the mirror is in the position AB, the image is at D in the highly hypermetropic eye and at C in the less hypermetropic eye. When the mirror is in the position A′B′ the respective images are at *d* and *c*. Since D*d* is less than C*c*, the higher the degree of error, the more rapid the movement of the shadow.

the higher the error, the nearer the image, and the smaller the excursion (Fig. 154).

The direction of the shadow is also noted: if it moves in the same direction as the mirror the patient is more hypermetropic than − 1 D, and if it moves in the opposite direction, the patient has a higher degree of myopia than this.

Digitized by Illinois College of Optometry Library

The horizontal meridian is tested first, and then the vertical. If the shadow moves with the mirror, progressively stronger convex lenses are placed in the trial frame until no shadow can be seen ; a slightly stronger lens (+ 0·25 D) is then added, and the shadow should be reversed. This shows that the error has been over-corrected, and definitely marks the point of neutralisation. At the point where there is no shadow at all we know that the refraction in this meridian has been exactly neutralised, and that the eye has been rendered myopic to the extent of — 1 D. If we therefore subtract 1 D from the value of the lens in the trial frame we get the refractive value in the meridian which we are examining.

Thus, if we find that both the horizontal and the vertical meridians show a faint rapidly moving shadow in the same direction as the tilt of the mirror when the + 3·5 D sphere is exhibited, show no shadow with + 3·75 D, and show a faint shadow in the opposite direction with a + 4·0 D sphere, we deduct 1·0 D and conclude that the refractive error is + 2·75 D. Similarly in myopia, if a — 3·5 D lens shows a faint shadow moving in the opposite direction, a — 3·75 D shows no shadow, and a — 4·0 D gives a reversal, we conclude that the refraction is — 4·75 D.

When the points of reversal in all meridians are the same, the refractive error is spherical. When the points of reversal

Fig. 155.—Oblique Retinoscopy Shadows in Astigmatism.

in different meridians are not the same, astigmatism is present, and the refraction in each should be corrected separately. When the axis of the cylinder is vertical or horizontal, the shadow moves horizontally or vertically across the pupil in the direction necessitated by the refractive

Digitized by Illinois College of Optometry Library

condition: thus, in mixed astimatism, it moves in opposite directions in the two. Where the axis of the cylinder is oblique, then the shadow appears oblique (Fig. 155).

The obliquity of the shadow depends on the direction of the axis of the cylinder, and is quite independent of the direction in which the mirror is tilted; this appearance is an optical illusion which is most easily explained pictorially

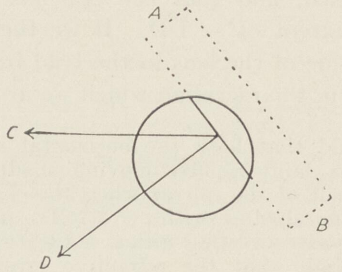


Fig. 156.—To Illustrate the Apparent Direction of Movement of an Oblique Astigmatic Shadow.

Fig. 157.—Retinoscopy Shadows in Astigmatism: the Band-shaped Shadow.

(Fig. 156). If an oblique ruler (AB) is slid across a circular opening in a horizontal direction (C), it will not appear to be travelling horizontally, but will appear to move obliquely (D) in a direction perpendicular to its own surface, and, no matter what the real direction of movement, this illusory direction will always be evident.

When these conditions which denote astigmatism are seen, the mirror is tilted in the two chief meridians which are respectively parallel and perpendicular to the edge of the

Digitized by Illinois College of Optometry Library

shadow. The more emmetropic meridian is corrected first, and then the mirror is tilted at right angles and the more ametropic meridian corrected. When the first meridian is exactly corrected, the illumination of the pupil assumes a band shape (Fig. 157), and on tilting the mirror parallel to this band, a shadow appears coming from both edges of the pupil at once to meet in the centre, leaving the peripheral parts of the pupil illuminated. This appearance is coincident with the exact neutralisation of the meridian at right angles to the band, the effect being due to the retinal images being converted into the form of lines.

The astigmatic error is calculated in the same way as the spherical, each meridian being estimated by itself. Thus if the point of reversal in one meridian is attained by a + 4 D lens, and in the other by a + 6 D lens, we deduct 1 D from each and arrive at an error of + 3 D sph. + 2 D cyl.

Similarly, if the two meridians are corrected by a + 2 D and a — 2 D lens respectively, deducting 1 D from each, we get + 1 D and — 3 D, and combining this into a sphero-cylindrical combination, we arrive at an error of + 1 D sph. — 4 D cyl., or — 3 D sph. + 4 D cyl. with the axis at right angles to the first.

If the axes of the two chief meridians are not at right angles, the refraction of the two chief meridians should be obtained in the usual manner, and the appropriate sphero-cylindrical combination calculated, as has been indicated on p. 52.

The direction of the axis of the cylinder can be told with a fair degree of precision from the direction of the edge of the shadow. This, however, can be determined more accurately if the appropriate sphere and cylinder are placed in the trial frame and the shadow effect again studied. Such a step is well worth while as it also affords a means of checking the estimated strength of the cylinder. Thus, if the refraction in one meridian was found to be + 3 D and in the other + 7 D, if a + 3 D sphere and a + 4 D cylinder are presented, there should be no shadow in any direction.

A further delicate test can now be applied *to verify the strength of the combination.* There is no shadow at 1 metre distance since the far point coincided with the

Digitized by Illinois College of Optometry Library

surgeon's eye. If now the latter bends forward so that he approaches the patient's eye by (say) 25 cm., the far point is now behind the surgeon's head, and a shadow moving in the same direction as the tilt of the mirror should appear. If the surgeon then leans back so that the distance between the two is 125 cm., the far point falls between them and a shadow moving against the tilt of the mirror should appear. If the expected change does not occur in both directions symmetrically, the spherical correction is wrong ; if it occurs in one direction and not in the other, the cylindrical correction is wrong.

Thus in the above example, if the refraction is really + 3·25 D sph. + 4 D cyl., on withdrawing from the patient, the shadow will be found to have moved with the mirror or to have disappeared in both meridians. If the correct refraction is + 3·0 D sph. + 4·25 D. cyl., there will be a band of light moving against the mirror in the direction of the axis of the cylinder, while in the direction of the astigmatic meridian the light will move with the mirror or will have disappeared. It is usually easy to attain an accuracy of ± 0·25 D in this way.

To verify the exact position of the axis, the appropriate sphere and a slightly under-correcting cylinder should be put up. Thus in the above example, a + 3 D sphere and a + 3·5 D cylinder should be placed in the trial frame. In this case, on rotating the mirror at right angles to the axis of the cylinder, a shadow (representing the + 0·5 D of uncorrected hypermetropia) should move exactly at right angles to the axis of the cylinder. If the cylinder is not in the proper direction this shadow will not move at right angles to the cylinder, but obliquely, and the direction of its obliquity will be considerably exaggerated. If the discrepancy in the strength is 0·5 D, it can be shown mathematically that the error in direction is multiplied six times. If the cylinder is under-corrected by 1 D, a stronger shadow will be obtained, but the error in direction will only be magnified four times. It is immaterial to the test whether the cylinder is under-corrected or over-corrected : thus in the above example, the

Digitized by Illinois College of Optometry Library

same effect would be produced by using a cylinder of + 4·5 D, but the shadow, of course, would move in the reverse direction.

Since the obliquity of the shadow multiplies any error in the direction of the axis to such an enormous extent, a very small deviation from the true axis is easily detected. The angle which the shadow makes with the axis of the cylinder can be roughly assessed, and the cylinder should be rotated through an angle one-sixth of this. The test should be again repeated, when any remaining error is as easily seen and corrected, until the final and correct position is attained. Such a test in practice takes very little time, and is an exceedingly valuable and delicate one, being especially useful where, for one reason or another, the subjective verification of the axis of the cylinder by the patient is not to be relied upon.

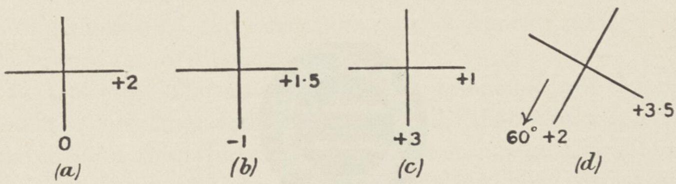


FIG. 158.—ASTIGMATIC REFRACTIONS.

(*a*) + 2·0 D cyl. ax. 90°.
(*b*) − 1·0 D sph. + 2·5 D cyl. ax. 90°, or + 1·5 D sph. − 2·5 D cyl. ax. 180°.
(*c*) + 1·0 D sph. + 2·0 D cyl. ax. 180°.
(*d*) + 2·0 D sph. + 1·5 D cyl. ax. 60°.

For example, if in the above case where the correction is a + 3 D sph. + 4 D cyl. axis 85°, a + 3 D sph. + 3·5 D cyl. is put up. Suppose the surgeon wrongly estimates that the direction of the axis is 90°, and he puts the cylinder vertically. On tilting the mirror in the horizontal direction, he will find that the shadow does not move horizontally, as it should, but that it runs obliquely at about 150°, as indicated on the trial frame. This shows that the cylinder is not set correctly, and since the shadow is diverted 30° from the horizontal, he must rotate the cylinder through one-sixth of this angle in the corresponding direction. He must, therefore, rotate it through 5° and change the axis from 90° to 85°.

Digitized by Illinois College of Optometry Library

When the final result has been obtained, it is usually written down as represented in Fig. 158. The lines represent the direction of the principal meridians if astigmatism is present, and where the error is spherical, they are drawn vertically and horizontally. The figures represent the true refraction, that is, the value of the lens actually correcting the meridian less 1 D.

Difficulties in Refraction.—Some refractions are easy; some are extremely difficult. It is an art which requires much painstaking practice and cannot be learned in a day; and it is only after the surgeon has done many retinoscopies that he can justifiably rely on his findings with any degree of safety. It is essentially practical and cannot be learned

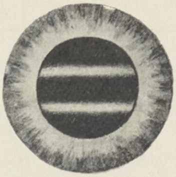


Fig. 159.—Scissors Shadows.

from text-books, but only under careful supervision in the routine of the out-patient department of a hospital.

Some special difficulties may be mentioned. It sometimes happens that the refraction varies in different parts of the pupil, the central part being different from the periphery. The appearance, of course, is accentuated with a mydriatic. The result is the formation of "scissors" shadows which meet each other and cross (Fig. 159). The best way to arrive at the approximate correction in this case is to find the lens which causes the two portions to meet in the centre of the pupil, attention being directed to the central part of the shadow to the exclusion of the periphery, for it is through this part of the pupil that vision is conducted. An irregular astigmatism or a tilting of the lens sometimes appears to give rise to the same condition.

Digitized by Illinois College of Optometry Library

In conical cornea the shadow is frequently triangular with its apex at the centre of the cone, and it appears to swirl round as the mirror is moved. In irregular astigmatism all sorts of distorted shadows may be apparent, which may move about in the most confusing manner. In such cases an approximate correction can often only be guessed, and in many, greatest reliance should be placed upon subjective tests. A stenopaeic slit may be placed in the trial frame and rotated into the position in which the patient sees best. This meridian is then corrected as far as possible with spherical lenses, and then the meridian at right angles is treated similarly, and the two combined in the appropriate sphero-cylindrical lens. In all these anomalous cases, however, the estimation of the refraction must become a matter for experience rather than precept.

Cycloplegia.—The advantages of a cycloplegic are these: that the accommodation is paralysed, that the pupil is dilated, and that the macular refraction can be estimated. The indications for its use have already been discussed (p. 198). Briefly, atropine should be employed in all young persons below sixteen years of age, and preferably in most hypermetropes below twenty. Otherwise homatropine is sufficient. In older patients this need not be used as a routine unless there is a suspicion that the accommodation is abnormally active; unless the objective findings by retinoscopy do not agree with the patient's subjective desires; unless definite symptoms of accommodative asthenopia are present, which do not seem to be explicable by the error found without a cycloplegic, or unless the pupil is small and the refraction presents difficulties. Sometimes a mydriatic is necessary in order to obtain the refraction of the macula, for example, in cases of high myopia when this region of the retina is involved in a posterior staphyloma. A mydriatic may also be indicated for ophthalmological purposes, in order to see the macula or the periphery of the lens.

When the pupil is dilated the retinoscopy is easier, and a

Digitized by Illinois College of Optometry Library

mydriatic should be used almost as a routine by the beginner. The fact that it does facilitate the estimation and make it more rapid makes it specially indicated in a busy and crowded hospital clinic, for there prolonged individual attention cannot always be given. Without its use the surgeon is to a certain extent dependent upon the co-operation of the patient, and it is advisable that the latter be able to participate intelligently by relaxing his accommodation: the mentality of the patient thus forms another indication for its preferential employment in hospital. It is to be remembered, however, as has been pointed out already, that the refraction under cycloplegia is a pathological one, and after the lens has assumed its normal shape, minute errors cannot reasonably be transposed to the dioptric system in the ordinary conditions of use. Where the optical conditions are good and the room large, where the surgeon is an expert and is prepared to spend a little time upon the estimation, and where the patient is reasonably intelligent, in the absence of the special indications already mentioned, I have no doubt that the ideal refraction is the one estimated in the absence of a cycloplegic.

It has already been mentioned (p. 203) that where atropine is given, it is prescribed for three days previous to the examination. A mixture of homatropine and cocaine is instilled about an hour or an hour and a half before the examination, and it is advisable that the oily solution be used (a small drop being given), or that the watery solution be employed at least three times at ten minutes' intervals, the tear duct being occluded by the finger at the time of instillation and for some moments afterwards.

Since homatropine frequently acts irregularly, and varies considerably in its efficacy between different individuals, a rough test should be made of the depth of cycloplegia by testing the accommodation before the refraction is done. It is useless to proceed with the retinoscopy until the amplitude of the accommodation has fallen to 1 D, that is,

Digitized by Illinois College of Optometry Library

until the reading test types are blurred at a distance of 1 metre. After the refraction has been estimated, it is advisable to test the amplitude of accommodation again to make sure that the effect of the drug has not worn off. In this case a + 3 D may be added to the distance correction, when the far point should be at 33 cm., and the near point slightly over 25 and never under 28 cm. After the examination is completed eserine should always be instilled.

The most important thing to remember in the use of these drugs is that they should be carefully employed in the aged, and never when glaucoma is suspected. In all cases the tension should be estimated and the disc examined before they are instilled, so that this, or the fear of this, can be reasonably excluded. Where any doubt is felt upon the matter the patient should not be allowed to leave observation until the pupil has again contracted under the influence of eserine.

The Ophthalmometer.—Some authorities advocate the use of the ophthalmometer for the estimation of astigmatic errors. The greatest recommendation of the instrument seems to be that with its aid the estimation can be done very rapidly in the hands of an expert. The saving of time, however, is gained at the cost of accuracy. It is to be noted that the astigmatic error only, not the spherical one, is determined, and that of the anterior surface of the cornea alone. It is also to be remembered :

(1) That the refraction of the posterior surface of the cornea is neglected. Tscherning has found that this sometimes amounts to about 0·5 D of astigmatism, usually against the rule.

(2) That the lenticular astigmatism is neglected ; this again may amount to 0·5 D or more.

(3) That the refraction of the central part of the cornea is not estimated, but that of two points about 1·25 mm. on either side of this point.

(4) That the reading does not give the cylinder required for correcting glasses, but the value of the cylinder which when placed in contact with the cornea would correct the astigmatic curvature of its anterior surface. When the lenses are worn 13 or 15 mm. away from the eye, their effective value is very different. It is true that the error is not great with

Digitized by Illinois College of Optometry Library

small lenses, but it varies in magnitude with each strength of lens, and may amount to as much as 3 or 5 D in the higher cylinders.

The scientific value of the ophthalmometer is considerable; but as a clinical instrument it is both misleading and inaccurate, and should never be relied upon, especially if importance is to be attached to the meticulous correction of astigmatic errors.

Digitized by Illinois College of Optometry Library

CHAPTER XXII

SUBJECTIVE VERIFICATION OF THE REFRACTION, AND THE TESTING OF THE MUSCULAR EQUILIBRIUM

Subjective Verification of the Refraction

The Distant Vision.—When the retinoscopy has been completed, the test types are illuminated and the visual acuity is tested with the appropriate lenses inserted in the trial frame. Each eye is tested separately while an opaque disc is placed in the other compartment of the frames, and then the two are finally tested together. In the great majority of cases the refractionist should aim at getting the vision up to the standard of 6/5, and if this is not attained he should satisfy himself that he is able to account for the visual defect ophthalmologically.

The patient is asked to read the test types, and the effects of slight modifications in the lenses are tried in each eye separately, any small change being made which gives a marked improvement in visual acuity. In the first place the position of the axis of the cylinder is verified by moving it to either side by 10° or 15°, when the change in either direction should produce an equal amount of blurring. A small + sphere should then be added (with a patient with good visual acuity a + 0·25 D is enough), and then a small — sphere, and the effect of each noted. A small + cylinder is then put up with its axis parallel to that of the cylinder in the trial frame, and then in a direction perpendicular to this, and the process is repeated with a corresponding — cylinder.

These last manœuvres are greatly facilitated by the use of Jackson's crossed cylinder (Fig. 160). The most convenient form is a combination of a — 0·25 D sphere with a

Digitized by Illinois College of Optometry Library

$+$ 0·5 D cylinder. The cylindrical axis is first placed in the same direction as the axis of the cylinder in the trial frame

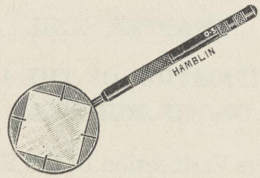


Fig. 160.—Jackson's Crossed Cylinders.

and then perpendicular to it. In the first position it enhances the effect of the cylinder by 0·25 D, in the second it diminishes it by the same amount. If the visual acuity is unchanged in either of these positions, the cylinder in the trial frame is correct.

The effect of these various combinations is the following :—

If we suppose that the estimated correction was $+$ 2·5 D sph. $+$ 2·0 D cyl. axis horizontal,

Adding + 0·25 D sph. makes the combination	+ 2·75 D sph.	+ 2·0 D cyl. ax. hor.
Adding − 0·25 D sph. makes the combination	+ 2·25 D sph.	+ 2·0 D cyl. ax. hor.
Adding + 0·25 D cyl. ax. hor. makes combination	+ 2·5 D sph.	+ 2·25 D cyl. ax. hor.
Adding + 0·25 D cyl. ax. vert. makes combination	+ 2·75 D sph.	+ 1·75 D cyl. ax. hor.
Adding − 0·25 D cyl. ax. hor. makes combination	+ 2·5 D sph.	+ 1·75 D cyl. ax. hor.
Adding − 0·25 D cyl. ax. vert. makes combination	+ 2·25 D sph.	+ 2.25 D cyl. ax. hor.

If the visual acuity is improved by any of these, the change should be made unless it is especially contra-indicated, and the verification repeated with the new combination by running through the cycle again.

It is not always easy for the patient to give definite answers with the use of the test types alone, especially in cases of small degrees of astigmatism. In these the results should be confirmed by the use of some type of astigmatic fan. The pattern most usually employed is the Maddox V test, or some modification of it (Fig. 161). It consists of a series of radiating lines arranged after the manner of the rays of

Digitized by Illinois College of Optometry Library

a rising sun, over which the V can be rotated through 180° by a pulley controlled from the part of the room where the surgeon is seated. When the cylindrical correction is removed from the trial frame and the spherical element left, the refraction in one meridian only is corrected. The line at right angles to this meridian therefore appears sharply defined and distinctly black, while the others appear blurred and grey.

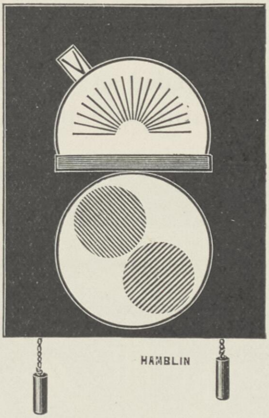


FIG. 161.—THE MADDOX V TEST.

The V is then rotated to the neighbourhood of this line, and the exact point of maximum definition is more accurately determined by comparing the relative intensity of the oblique lines forming the limbs of the V. By rotating the V slightly in the direction of the blacker limb, an intermediate position is then reached when the two limbs appear equally distinct. This denotes the direction at right angles to the exact axis of the correcting cylinder (see p. 126). The points of maximum definition and maximum blurring may be more easily appreciated by observing the two discs represented below the fan on the figure, the one with lines arranged at right angles to the other, which is also rotated simultaneously with the V. If they are not equally distinct,

Digitized by Illinois College of Optometry Library

the cylinder should be slightly modified until they are. The appropriate cylinder is then inserted in the trial frame in this axis, which, of course, should correspond, or nearly so, with that already found, whereupon all the lines on the chart should appear equally distinct.

Friedenwald suggested a slight modification of this test which is susceptible of greater accuracy, wherein the lines are drawn upon a grey background.[1] In this case the line corresponding to the axis of astigmatism is clear, while the other lines, instead of being merely blurred as in the usual black-and-white test, become merged into the grey background and are practically invisible.

This test can be extended so as to be considerably more accurate and useful if the lines are made to appear in two

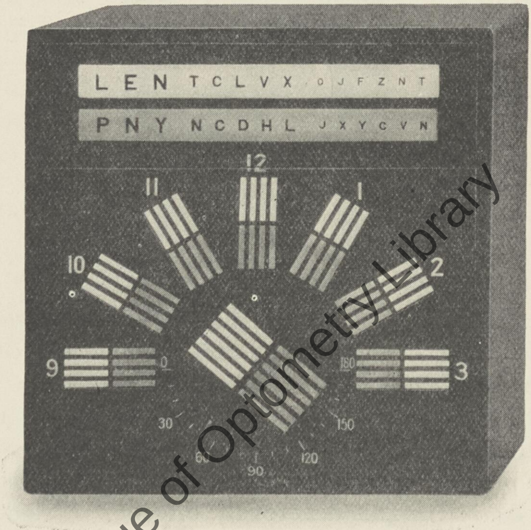


FIG. 162.—THE DUOCHROME.

different colours of markedly different wave lengths. When discussing the phenomena of chromatic aberration (p. 65) we saw that the blue rays, having a short wave length, were

[1] Embodied in Hamblin's "1925 Astigmatic Test."

Digitized by Illinois College of Optometry Library

refracted more acutely and brought to a focus sooner than the long red waves. If the eye is corrected so that it is exactly emmetropic, a focus is formed between these two extremes, if it is myopic the red is seen more distinctly, if it is hypermetropic the blue is more sharply defined. These principles form the basis of the well-known test with cobalt-blue glass, which allows only blue and red rays to pass through it ; and they have been incorporated lately to include an astigmatic test in an apparatus known as the duochrome (Fig. 162).[1] With its aid the strength of the correcting lenses can also be verified with great precision. We have seen that it should be possible to attain an accuracy of one quarter of a dioptre by retinoscopy, which can usually be verified within this limit on the test types ; with this apparatus it is usually possible to reduce the margin of error to one-eighth.

The test makes use of lines of two colours which are obtained by transillumination through two types of glass, one coloured red and the other coloured green. In the normal eye the red will be focused behind the retina and the green in front. The glasses are so chosen that their maximum transmission is equally spaced on either side of the yellow, which, it will be remembered, the eye focuses preferentially, and the colours are such that the linear difference in their focus is 100 $\mu\mu$ (Fig. 163). Theoretically, therefore, only an eye which is normal to within 0·06 D will be able to express a preference for either colour. With practically monochromatic light much of the aberration of white light is eliminated, and the image is either sharply in focus or definitely blurred, and thus an alteration of one-eighth of a dioptre usually produces a change so marked as to be easily appreciable. The greatest asset of the test is its purely comparative nature, for when the two foci are presented to the eye simultaneously and are both approximately equally clear, it will not attempt to focus the one at the expense of the other; although accommodation is not abolished completely, much of the stimulus to accommodate is therefore lacking.

On top of the apparatus are two lines of types, half upon an illuminated green background and half upon a red, below which is the typical fan arrangement of radial lines grouped in blocks of green and red, together with a revolving block of similar lines. The estimated spherical correction should remain in the trial

[1] Made by Clifford Brown, Wigmore Street, London, W.

Digitized by Illinois College of Optometry Library

frames, and the fan is manipulated as has already been described by illuminating the radial lines and adjusting the revolving blocks to the position of optimum definition. The axis of the least ametropic meridian is thus found, that is, the value of the spherical correction. At this point the two sets of lines should appear equally distinct ; if the red appears more distinct, the refraction in this meridian is still myopic and spherical lenses of — 0·12 D should be added to the trial frames until they appear equal. If the green is the more distinct, similar small + lenses should be added. The disc is then rotated to a position at right

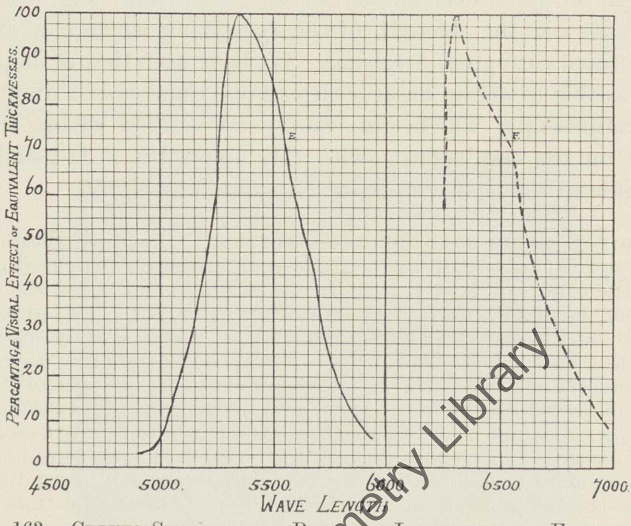


Fig. 163.—Curves Showing the Relative Intensities of Equivalent Thicknesses of Red and Green Glass as used in the Duochrome.

angles, and the estimated cylindrical correction is inserted in the axis already determined. If it is of the correct magnitude, the red and green lines in the disc should again appear equally distinct. If they are not, suitable corrections of $\pm$ 0·12 D should be presented until they are. The lines of letters are then illuminated, and any minor adjustment made in the axis to give the best definition.

Such a method, of course, should never be relied upon alone to estimate the refraction ; the essential test should always be retinoscopy, and this should be reserved only for the final minute adjustment. In practice its use may present some difficulties to patients with large errors, particularly when these

Digitized by Illinois College of Optometry Library

are astigmatic. Its greatest value—and a very real one—is in the correction of minutiae.

We have now arrived at the final verified correction for the refraction of each eye separately. As a rule, when binocular vision is tested, it will be found that an additional + 0·25 D sphere is easily tolerated and may even be an advantage. The test, however, is carried out at a distance of 6 metres instead of (theoretically) at infinity, and to allow for the small amount of error thus introduced at this distance, an allowance of one-sixth of a dioptre should be deducted. The final glass therefore remains approximately the same, or at most, one-eighth of a dioptre only should be added. On this basis the correction for distant vision should be ordered.

The Ordering of Glasses for Distance.—The principles underlying the final choice of glasses have already been discussed in the appropriate chapters of this book. Other things being equal, it is usually indicated that the fullest correction consistent with good vision should be ordered, and especially is this necessary when the error is small and the symptoms are those of eye-strain rather than of defective vision. It will be remembered that in very high degrees of ametropia, especially of myopia, the full correction may not be tolerated, and an under-correction is usually necessary.

When a mydriatic has been used, a deduction must be made to allow for the normal tone of the ciliary muscle, which has been temporarily abolished. In many cases, especially when the error is large, it is well to have a subsequent post-cycloplegic test after the effect of the drug has passed off. In any case, this will be necessary after the presbyopic age has been reached, unless an arbitrary glass is ordered for reading—an unsatisfactory and dangerous proceeding. When, however, the visual acuity with the manifest hypermetropia has been determined before the mydriatic is instilled, as has been already advised, it is frequently possible to make an allowance for the artificial state of cycloplegia, and, by combining the information

Digitized by Illinois College of Optometry Library

derived from both examinations, to prescribe the glasses at once. The subsequent test need not therefore become a routine, but whenever any doubt is felt it should be insisted upon. Some essential principles may be recapitulated.

When atropine has been used in children it is usual to deduct 1 D from the full correction; if the glasses are intended as a means of treatment for convergent squint, 0·5 D only should be deducted, and in high degrees of myopia any deduction may be inadvisable. When homatropine has been employed, 0·75 D in hypermetropes, 0·5 D in emmetropes, and 0·25 D or nothing at all in myopes, depending on the degree of error, will be found sufficient. A smaller reduction is made because, as has already been pointed out, homatropine does not fully abolish the ciliary tone, and it will be remembered that this muscle is more fully developed in hypermetropia than in myopia. In higher degrees of hypermetropia, the fullest correction compatible with comfort should be ordered unless it is contra-indicated (see p. 224); this may be assessed from the manifest hypermetropia, but, particularly if there is in addition a large cylindrical error, a subsequent post-cycloplegic test is advisable. The lower degrees of myopia should be fully corrected, and in the higher degrees the amount which is to be deducted must usually be left to a post-mydriatic test. Astigmatism should be corrected in full with the reservations already pointed out (see p. 130). In cases of mixed astigmatism it may be advisable to have the subsequent test in order to see which combination is most comfortably borne; and in high degrees of anisometropia, when a compromise between the two eyes is to be tried (see p. 142), a post-mydriatic test is essential.

The Determination of the Accommodation and the Tests for Near Vision

When the glasses for distance have been determined in the manner already described, attention is turned to the near

Digitized by Illinois College of Optometry Library

vision. In the first place the power of accommodation should be tested as a routine; the tests are easily and rapidly done, and it is only upon the basis of these that reading glasses should be prescribed.

During these tests the full correction for distant vision should be retained in the trial frames: they form a measure of the far point. The near point is then determined.

The Determination of the Near Point.—This may be done in a rough, but fairly efficient manner, by asking the patient to bring the reading test types close up to his eyes until the smallest print appears blurred. With print, however, it is difficult to differentiate between blurring, which marks the near point of accommodation, and diplopia, which marks the near point of convergence. A more accurate method, which involves little additional time, is to use the *accommodation card* of Duane. This, as we have noticed already (Fig. 88), is a white card (such as a visiting card) upon which a black vertical line is drawn. It is brought up to the eye until it appears blurred.

In young subjects, in whom the accommodation is very active, a − 3 D or − 4 D sphere should be added to the distance correction in order to carry the near point a convenient distance away, and in high hypermetropes and presbyopes, plus lenses should be added to bring it within measurable distance. These, of course, have to be added to, or deducted from the final value. The distance at which the object appears blurred is then measured from the point at which glasses are to be fitted, that is, at a point usually about 14 mm. in front of the cornea. The distance is measured in centimetres, or more conveniently by means of a Prince's rule, in dioptres. If it is measured in centimetres, the dioptric value of the reading is the reciprocal of the length expressed in metres: thus a distance of 25 cm. represents 100/25, or 4 dioptres.

The distance is measured by a tape held at the outer canthus of the eye; looking from the side, the surgeon estimates the level of the anterior summit of the cornea, and, deducting this distance plus 14 mm. from the total measurement to the accommodation card, he obtains the measurement to the near point. Duane

Digitized by Illinois College of Optometry Library

introduced a very useful *accommodation rule* to act as a measure. It is a modification of Prince's rule, and consists of a straight wooden ruler placed between the eyes with a groove cut at the end to fit the bridge of the nose. It is calibrated along the top and down the sides to serve binocular and uniocular measurements, and is marked in centimetres to register the near point, and in dioptres to register the amplitude of accommodation, the scale commencing at a distance 14 mm. in front of the cornea. As the accommodation card is approximated to the eye its distance can be read off in centimetres, and translated simultaneously into dioptres of accommodative power.

The near point should be measured with each eye singly while the other is occluded by an opaque disc ; then both eyes should be uncovered and the binocular accommodation estimated, the patient being asked at the same time to converge. The binocular result is usually about 0·5 D greater.

At the same time the near point of convergence may be measured. When this is reached the line appears double. It may be reached simultaneously with the near point of accommodation when the doubling and the blurring appear together ; it may be reached first, in which case the image becomes double while yet clearly outlined ; or it may be the nearer of the two to the eye, when the line becomes blurred and subsequently doubles. In any case the patient should be instructed to differentiate between the two phenomena. The surgeon can verify the observation by watching for the point at which one eye begins to deviate outwards (see p. 219).

The Determination of Glasses for Near Work.—We have seen that the accommodation varies with age (p. 188). At the age of ten the near point may be 7 cm. away and the amplitude of accommodation 14 D, while at the age of eighty the near point and the far point may coincide and the amplitude may be *nil*. We have also seen that if comfort is to be maintained, a certain amount of accommodative power must be kept in reserve, so that special glasses are required for near work whenever the near point approaches the distance at which the work is habitually done. When the patient's

Digitized by Illinois College of Optometry Library

symptoms indicate that such a course is necessary, the near point is determined with the distant correction still in place. He is then given the reading test types and asked to hold them at the distance at which he is accustomed to work or read. In the great majority of cases below the age of forty-five, unless there is a high degree of myopia, or an insufficiency of accommodation (see p. 192), the types will be easily read. Where they are not, appropriate convex lenses should be added to the distant correction so that the near point is brought within the working distance, and the types are easily and comfortably read.

The procedure to be adopted has already been described in detail on p. 183. The amplitude of accommodation is obtained by subtracting the dioptric value of the far point from that of the near point ; one-third of this is kept in reserve, and lenses are added to give the necessary amplitude. Let us suppose, for example, that the distant correction is + 1·0 D, and that the near point is 33 cm., (*i.e.*, is equivalent to 3 D) ; therefore, keeping one-third in reserve to ensure comfort, the available amplitude of accommodation is 2 D. To read at 28 cm., 3·5 D (100/28) of accommodation are required, that is, an addition of + 1·5 D to what is available. This, therefore, is added to the distant correction, making the reading glass one of + 2·5 D.

Presbyopic glasses should never be prescribed mechanically by ordering an approximate addition varying with the age of the patient. Each patient should be tested individually and the accommodation in each eye estimated separately. Where there is a difference in accommodative power between the two eyes, a stronger addition to the weaker eye should be given. The individual variation is large, and those glasses should be ordered in each case which give the most serviceable and comfortable, not necessarily the clearest, vision, and which, when there is any accommodation present, keep the working distance within the near point.

In all cases it is better to under-correct than to over-

Digitized by Illinois College of Optometry Library

correct, since, if the glasses tend to be too strong, difficulties will be experienced with convergence, and the range of vision will be very limited. In any case a glass which brings the near point closer than 28 cm. is rarely well borne (that is, a total power of 3·5 D), and if for any reason the demands of fine work require a higher correction, the convergence should be aided with prisms as well as the accommodation with spheres.

Chalmers and Percival have pointed out that if the same glasses are to be used by a non-presbyope for distance and near work, an error is introduced owing to the fact that in the first case the incident rays of light are parallel, while in the second they are divergent. In order that the latter may be converged to the same focus so that they fall upon the retina, a stronger correction is required than is indicated by the refraction. For a working distance of 30 cm., the strength of the distance lens must be increased by about 9 per cent. Thus a + 3·0 D sphere for infinity is optically equivalent to a + 3·27 D sphere for 30 cm., while the wearer still uses 3·3 D of accommodation. In a presbyope, however, the additional spherical element required for near work has the effect of making the incident light more nearly parallel, and consequently a smaller correction factor is required. When a + 1·0 D sphere is added, the correcting factor is 6 per cent., when a + 2·0 D sphere is added the correction is 3 per cent., and when + 3·0 D sphere is added the incident rays become practically parallel and no correction is required. (See Appendix IV.)

The practical importance of this lies in cases of high cylindrical corrections; for in many of these, if the same glasses are used for reading as for distant vision, the result is unsatisfactory. Thus if a + 5·0 D cylinder is required for distance, a + 5·5 D cylinder is required for near work. To secure adequate centring, we shall see later (p. 359) that a special pair of reading spectacles is usually advisable when the astigmatic error is high, even in non-presbyopes, and the

Digitized by Illinois College of Optometry Library

opportunity should be taken of incorporating this correction in these.

Mention has already been made of the slight amount of cyclophoric extorsion which usually occurs when the eyes are converged (see p. 221). A slight rotation of a high cylinder, particularly if it is oblique, can be made in the reading glasses in order to neutralise this, thus adding considerably to the comfort of the patient, as well as increasing his visual acuity for close work.

It will be found that the great majority of people retain some accommodation until about seventy years, and therefore it is unnecessary to prescribe a higher addition than + 3·5 D until a very advanced age. The glasses, of course, must be varied with the nature of the work which is to be done, and if the patient wishes to see at two different distances relatively farther apart than the amplitude of the accommodation remaining to him allows him to cover, he must be provided with two pairs of glasses for near work. Thus, for example, glasses may be required for reading, for working, or for music.

If near work with the reading glasses is still giving rise to trouble which cannot obviously be explained, the relative accommodation and convergence should be investigated at the working distance see (pp. 175 and 177). If the relative accommodation is deficient, the spherical addition for the working glasses should be altered ; if the patient is working outside the " area of comfort " of his convergence a prismatic correction should be ordered which brings his convergence within it.

The Determination of the Muscle Balance

The next step in the examination is to test the state of the balance of the ocular muscles. Some preliminary tests have already been made in the initial external examination, but, as they are important in the present

Digitized by Illinois College of Optometry Library

connection, they may be mentioned again for the sake of continuity.

Inspection and tests for mobility.—Inspection shows whether the axes of the eyes are approximately parallel and if they look straight ahead. Any marked degree of squint is thus excluded. The patient is then asked to look at the surgeon's finger moved about in front of him, when a paralytic squint will be suggested by a failure of movement in one direction.

The *binocular fixation* is then tested. The patient is asked to look at an object (*e.g.*, a point of light) 6 metres in front of him, and a card is then held before one eye and then passed quickly across so as to occlude the other. If neither eye deviates when covered, but each remains steadily looking in the same direction, there is effortless binocular fixation and good muscle balance. If a squint appears to be present in these circumstances, it is therefore an *apparent squint*, and is due to a large angle gamma (p. 69) or to some deformity such as epicanthus.

If either eye, when covered, deviates from its original position, while the other remains still in the line of fixation, and when it is uncovered, turns back again into the fixing position, binocular fixation is only attained under the stimulus of binocular vision, and a state of muscular imbalance, or *heterophoria* is present.

If either eye when it is covered, deviates, and at the same moment the other moves in any direction to take up fixation, there is no binocular fixation and a *true squint* is present. If the deviations suffered by both eyes are equal when they are thus covered (that is, if the primary deviation equals the secondary deviation, see p. 233), the squint is *concomitant*. Otherwise it is *paralytic* (see p. 231).

In very young children this test will be found impossible ; but the presence or absence of a squint can be determined by reflecting the light with an ophthalmoscope into their eyes. Even an infant will fix a light reflexly. If the reflection occu-

Digitized by Illinois College of Optometry Library

pies the centres of both corneae, there is no squint present; if it does not, but appears more eccentric in one than can be reasonably accounted for by a large angle gamma, squint is present. It is to be remembered, of course, that very young infants in whom binocular fixation has not yet developed exercise little or no co-ordinated control over the movements of their eyes. Before the age of six months, and sometimes later, the eyes normally deviate independently of each other.

We can now divide the patients into two categories—those in whom binocular fixation exists, and those in whom it does not. Those in the first class are to be subjected to finer tests to discover the presence of muscular imbalance or latent squint, those in the second are to have the nature and degree of their true squint investigated.

The Investigation of Heterophoria.—The tests which have been suggested to investigate heterophoria are legion. They all depend upon the same principle—that of dissociating the images in the two eyes so that the stimulus for binocular vision is removed and the eyes take up the position of rest. This can be done in many ways; by producing a diplopia with prisms, as suggested by von Graefe, a procedure which has been incorporated in Stevens' phorometer; by separating the two visual fields by a diaphragm, which forms the basis of Harman's diaphragm test; and so on. The easiest, most accurate, and most generally applicable test, however, is that of the Maddox rod; and it alone will be discussed.

The Maddox rod (Fig. 105) has already been described. It will be remembered that it consists of one or more cylinders of red glass set in a frame. A point of light, when viewed through it, appears as a long thin red line running in the direction at right angles to the long axis of the cylinders.

To test the muscle balance for distant vision the patient remains seated in the chair still wearing his correcting lenses, and it is essential, of course, that the centring of these be exact. A small point of light is situated 6 metres off: it is

Digitized by Illinois College of Optometry Library

usually possible to incorporate this in the box of test types as seen in Fig. 119. The Maddox rod is then placed in the right cell of the trial frame with the cylinders running in the horizontal direction. The left eye is temporarily covered up in order that the patient can see quite distinctly the nature of the red line running vertically up and down the

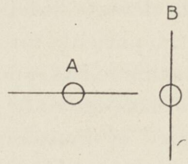


Fig. 164.—(A) Orthophoria in the vertical direction; (B) Orthophoria in the horizontal direction.

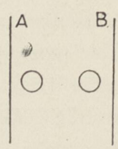


Fig. 165.—(A) Exophoria; (B) Esophoria.

Fig. 166.—(A) Right hyperphoria; (B) Left hyperphoria.

Figs. 164, 165 and 166.—The Maddox Rod Test for Heterophoria. Relative Positions of the Point of Light and the Red Line when the Maddox Rod is in Front of the Right Eye.

room, and then, when the left eye is again exposed, the patient is asked to look at the light and say whether the red line is running through it or to one or other side.

If there is orthophoria in the horizontal direction the red line will run through the light (Fig. 164, B); if exophoria is present the line will be to the left of the light (Fig. 165, A); if esophoria, to the right (Fig. 165, B). The amount of deviation is then measured on a " tangent scale " (Fig. 167)

Digitized by Illinois College of Optometry Library

which registers the deviation directly; or it is estimated by placing prisms in the other cell of the trial frame with their bases in or out, until the line is made to run through the light. The Maddox rod is then rotated at right angles, when a horizontal line is seen. If this runs through the light, there is no hyperphoria (Fig. 164, A); if the red line appears below the light there is right hyperphoria (Fig. 166, A); if above, there is left hyperphoria (Fig. 166, B). The

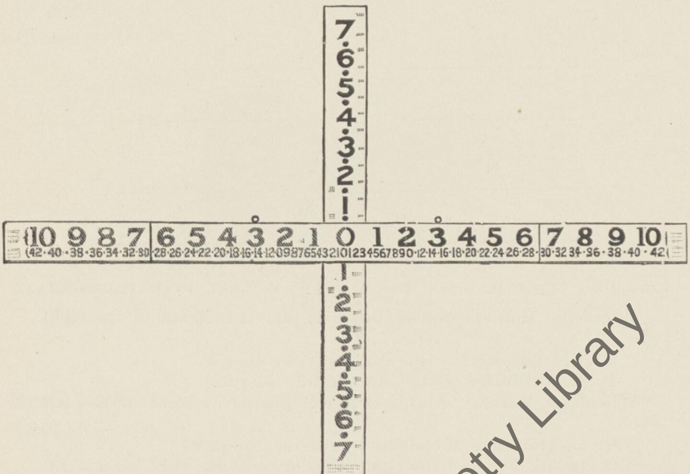


FIG. 167.—THE MADDOX TANGENT SCALE.

deviation is again measured by neutralising the displacement of the red line by prisms until the line runs through the centre of the light: in all cases, since prisms displace objects in the direction of their apices (Fig. 7) the prism placed in front of any eye must have its apex pointing in the direction of the displacement of the red streak.

If cyclophoria is present, when the Maddox rod is vertical, the red line, instead of running horizontally, will run obliquely; and the number of degrees through which the rod has to be tilted in order to make the line of light appear

Digitized by Illinois College of Optometry Library

vertical will indicate the amount of torsion. The obliquity is more easily recognised if two Maddox rods are used, one placed before each eye, when two red lines are seen, which, in the absence of cyclophoria, are parallel to each other. Great care must, of course, be taken that the rods are set absolutely vertically in the trial frame. If there is a definite divergence it is well to investigate it further by the *Maddox double prism.* This consists of two weak prisms of about 3° or 6° placed base to base in a metal rim which is of the

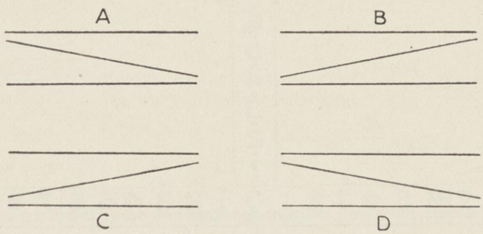


Fig. 168.—The Maddox Double Prism Test in Cyclophoria.

When the Maddox double prism is placed in front of the right eye :

A. Insufficiency of the left superior oblique.
B. Insufficiency of the left inferior oblique.

When the Maddox double prism is placed in front of the left eye :

C. Insufficiency of the right superior oblique.
D. Insufficiency of the right inferior oblique.

standard size to fit into a trial frame. It is set before one eye with the base line between the prisms horizontally on the level of the visual axis ; and, with one eye covered up, the patient looks at a horizontal line drawn on a card 40 cm. away. The two prisms produce the effect of uniocular diplopia, so that two parallel horizontal lines are seen, displaced equally above and below. The other eye is then uncovered, when a third line is seen between the other two in the position of the line on the card. In the absence of cyclophoria the three lines are parallel ; if it is present, the middle line will run in an oblique direction (see Fig. 168). When

Digitized by Illinois College of Optometry Library

the Maddox double prism is placed in front of the right eye, if the right end of the middle line dips, there is insufficiency of the left superior oblique, if the left end dips there is insufficiency of the left inferior oblique. With the prism in front of the left eye, if the left end dips there is insufficiency of the right superior oblique, and if the right end dips there is insufficiency of the right inferior oblique.[1]

The *muscle balance for near vision* must now be tested, and here again the patient wears his correcting lenses, this time, of course, with the addition for near vision. Here again many tests are available, but the best is the Maddox wing

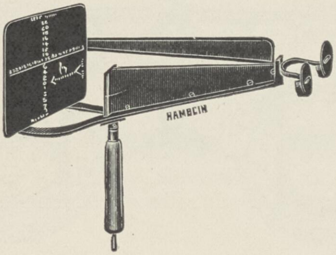


Fig. 169.—The Maddox Wing Test.

test (Fig. 169). With it every type of heterophoria is investigated at a distance of one-third of a metre.

When the patient looks through the two slit-holes in the eyepieces of the instrument, the fields which are exposed to each eye are separated by a diaphragm in such a way that they glide tangentially into each other. The right eye sees a white finger pointing vertically upwards and a red arrow pointing horizontally to the left. The left eye sees a horizontal row of figures in white and a vertical row in red ; these are calibrated to read in degrees of deviation. The finger pointing to the horizontal row of figures and the arrow pointing to the vertical row should both be at zero ; any deviation there may

[1] These conclusions are suggested by Savage ; but it is to be noted that they are not universally accepted. Some authorities consider the divergence elicited physiological.

Digitized by Illinois College of Optometry Library

be records an eso- or exophoria or a hyperphoria, the amount of which can be read off on the scale.

Finally, the strength of the muscles should be estimated by forcing them to act against prisms to the limit of their power. The converging power varies very much and with practice can be raised to the neighbourhood of 50 degrees (25° *d*) or more; if it falls below 15 degrees, it may be taken to be definitely insufficient. The diverging power

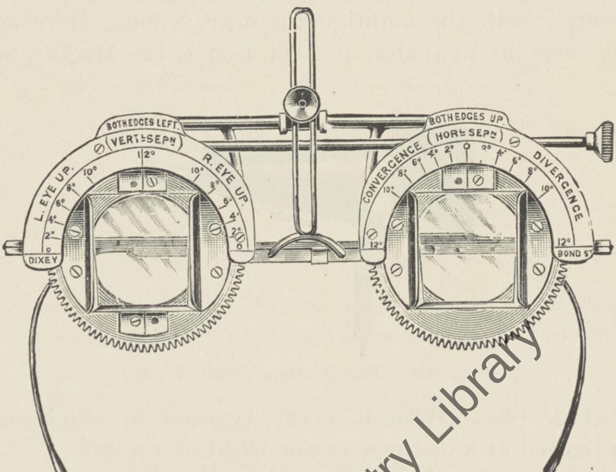


FIG. 170.—THE MADDOX PRISM VERGER.

should be 4 to 5 degrees, and the normal limits of super- and sub-duction are from 1·5 to 2·5 degrees. Their *vergence power* (see p. 213) is thus found by putting gradually increasing prisms in front of the eye in various directions until diplopia is produced. The test should be carried out with the patient wearing his full correction. He should fix a point of light at 6 metres distance, and indicate at once when it appears double.

The test is most easily done by a *Maddox prism verger* (Fig. 170). The prism verger [1] is composed of two prisms each of 6° *d*, 6 ▽, or

[1] Obtainable from C. W. Dixey & Son, New Bond Street, London, W.

Digitized by Illinois College of Optometry Library

12 ▽, mounted on a frame so that they can be rotated simultaneously in opposite directions by turning a milled head. One of the prisms can be removed and introduced in the reverse way, so that it can be used for vertical as well as horizontal vergence. The effect of the two prisms taken together is the same as that of two superimposed rotating prisms, but when they are distributed between the two eyes the distortion effects are less. When they are lying apex to base the combination becomes a glass plate and the prismatic effect is *nil*; when they are lying with their two bases in corresponding positions the total effect is equal to double the effect of one; and each intermediate position has an intermediate prismatic value. The deviations are calibrated on a scale, those on one eye recording horizontal displacements, those on the other vertical.

The horizontal vergence is measured first. The reversible prism is inserted apex upwards, and the milled head rotated counter-clockwise; this causes the edges of the prisms to rotate outwards, thus producing a divergence of the visual axes and measuring the patient's diverging power. The milled head is then rotated in the opposite direction, and the converging power similarly estimated. The reversible prism is then removed and inserted base upwards, and the milled head is rotated until both apices point to the left. The milled head is now rotated counter-clockwise, causing a relative elevation of the right eye, while rotation in the opposite sense will cause a similar elevation of the left.

By means of these tests we can thus discover the state of the muscle balance for distant vision and for near vision, and at the same time, we can get some information as to the nature of the deficiency. In exophoria, if the defect is greater for distant than for near vision, there is divergence-excess; if it is greater for near than for distant vision, there is convergence-insufficiency. Conversely, in esophoria, if the defect is greater for distance than for near vision, there is divergence-insufficiency; if it is greater for near than for distant vision, there is convergence-excess. The extent of the anomaly is indicated by the results of the tests of the verging power.

The indications for the treatment of muscular imbalance have already been outlined (see p. 223). It may be well to repeat here that moderate hyperphoria, when giving rise to symptoms, can always be corrected in full. Greater

Digitized by Illinois College of Optometry Library

hesitation, however, should be felt in correcting a horizontal deviation. The refraction should always be corrected, and, if present, any vertical error as well; the horizontal error then frequently rights itself if the general health receives attention. In esophoria the hypermetropia is fully corrected, and the more fully the element of convergence-excess enters into the case, the fuller should be the correction. In exophoria the tendency should be to under-correct the refractive error; and when convergence-insufficiency is present, the reading addition should be as weak as possible. Failure to observe this recommendation accounts for much discomfort. Prisms, when they are ordered, should always

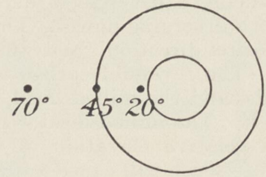


Fig. 171.—Measurement of the Angle of Squint.

The light is thrown into the squinting eye, and the sound eye maintains fixation; if the reflection is on the margin of the pupil the angle of squint is approximately 20°; if it falls upon the limbus, it is approximately 45°.

tend to under-correct, and they should be designed to meet the case at the distance for which the glasses are to be used.

The Investigation of Heterotropia.—When the presence of a true squint has been decided upon it is advisable from the point of view of prognosis, and in deciding the course of treatment to adopt, to determine whether it is unilateral or alternating, constant or periodic. The method employed has already been noticed (see p. 242).

The *binocular vision* is then investigated by the amblyoscope if the patient is old enough to make use of it, and by this means the degree of development of the fusion sense can be ascertained—whether uniocular vision alone exists, or

Digitized by Illinois College of Optometry Library

merely simultaneous perception, or partially developed fusion (see p. 210).

Again, as an aid in indicating appropriate treatment, and also as a guide as to the benefit which may accrue from

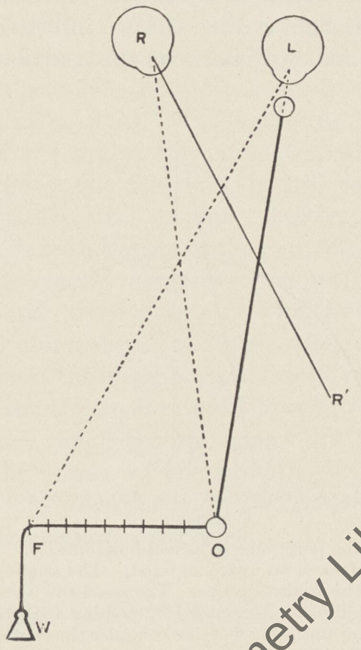


FIG. 172.—THE PRIESTLEY SMITH TAPE.

R is the right eye with an internal squint; L, the left (sound) eye; O represents the ophthalmoscope; OF the graduated tape; F, the surgeon's finger (the fixation point); W, the weight keeping the tape OF taut. The angle measured is OLF, which is equal to ORR′, the angle of squint.

its application, it is useful to obtain an accurate measurement of the degree of the deformity. This should be estimated by *measuring the angle of the squint.* A rough indication can be obtained, as was suggested by Hirschberg, by throwing a light into the squinting eye from the ophthalmoscopic mirror from a distance of 2 metres, while the other eye maintains

Digitized by Illinois College of Optometry Library

fixation, and noting *the position of the corneal reflex* (Fig. 171). This can be done even in the youngest children, since an infant will fix a light reflexly. The fact that it is so fixing is first verified by throwing the light into the good eye and noting that the reflex occupies the centre of the pupil, or nearly so. The light is then thrown into the squinting eye: if the reflex is half way between the centre of the pupil and

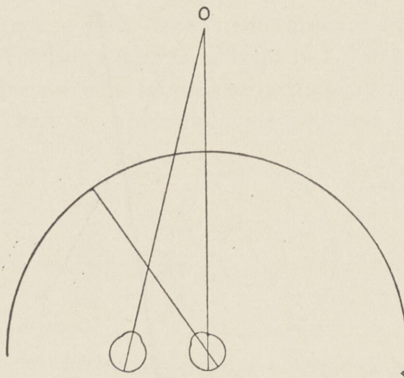


FIG. 173.—THE MEASUREMENT OF THE ANGLE OF SQUINT BY THE PERIMETER.

The arc of the perimeter is turned horizontally. The object, O. situated 6 metres or so away, is fixed. The angle gamma is first measured in the squinting eye. The good eye then fixes O, and the angle of squint is determined by passing a light round the arc of the perimeter until its reflection occupies the centre of the cornea of the squinting eye.

the corneal margin, there is a deviation of approximately 15 to 20 degrees, and if it falls upon the limbus, the deviation is about 45 degrees.

The most accurate test in young children is by means of *Priestley Smith's tape* (Fig. 172). This consists of a tape 1 metre long at each end of which is a ring. One ring is held under the patient's fixing eye and the surgeon puts the other through the handle of his ophthalmoscope, keeping the tape taut. With his disengaged hand he holds the calibrated tape which is also attached to the second ring, and kept taut

Digitized by Illinois College of Optometry Library

by a weight. The patient is then asked to look at an outstretched finger of this hand, while the light is thrown from the ophthalmoscope into the squinting eye. The surgeon then moves his hand slowly outwards allowing the tape to slip between the finger and thumb, the patient fixing it the while, until the corneal reflex is in the centre of the pupil. At this point the angle of the squint is read off on the tape.

The *perimeter* provides the most accurate measure in the case of adults (Fig. 173). The squinting eye is placed in the centre of the arc of the perimeter, which is turned horizontally towards the side to which the squinting eye is directed. The patient fixes an object 6 metres away, his line of vision running above the arc of the perimeter. In the first place the angle gamma is measured : the good eye is covered and the patient fixes the distant spot with the squinting eye ; a light is passed round the arc until the reflex is in the centre of the cornea, when the angle gamma is read off on the scale. The good eye is then uncovered and allowed to fix the object ; the light is passed round the arc again until the reflex is in the centre of the cornea of the squinting eye. The angle is now read off, and when the angle gamma is deducted from it the angle of the squint is obtained.

SUMMARY OF CLINICAL METHODS

The description of clinical methods detailed in this section may give the impression that the adequate examination and correction of the vision is a lengthy and complicated proceeding. On the contrary, it is not. Most of the tests take much longer to describe than to carry out in practice ; and when practice becomes a routine, and long custom makes their execution automatic and their interpretation instantaneous, they can be performed surprisingly rapidly and at the same time accurately. When patients are examined individually, a skilled surgeon rarely requires longer than half-an-hour to complete his examination.

Digitized by Illinois College of Optometry Library

When patients are seen in large numbers in a hospital clinic, the most convenient method is to complete the external examination of the eye and test the visual acuity and the manifest hypermetropia in the lighted room, many patients being dealt with at a time. They are then transferred to the dark room where the examination by focal illumination, by the ophthalmoscope, and the retinoscopy is done. On then returning to the first room the remaining tests are completed.

When patients are examined individually the following routine is suggested, as it saves the maximum amount of time and entails the minimum of movement. After the history has been taken, the patient should be seated in a large room which can be darkened and he need never be required to move: most patients move slowly. The following steps should then be gone through :—

1. External examination in diffuse light.
2. Examination of the motility of the eyes.
3. The card test to elicit heterophoria and squint.

> This is best done at this stage, before the trial frames are put on. It saves them being taken off subsequently, and, in addition, the detection of a squint may account for a marked deficiency of vision in the deviating eye, which, if it is not recognised early in the examination, may give rise to some concern.

The room is now darkened and the trial frames are put on and centred.

4. The testing of visual acuity, uniocularly and binocularly.

5. The estimation of the manifest hypermetropia, uniocularly and binocularly.

6. The testing of the acuity for near vision, uniocularly and binocularly.

7. The examination of the eyes by focal illumination, and by the plane mirror, and the ophthalmoscopic examination by the indirect and direct methods.

Digitized by Illinois College of Optometry Library

8. The retinoscopy, and its verification with the sphero-cylindrical combination.

9. The verification of the retinoscopy with the test types and then with the astigmatic fan.

10. With the full correction in place, the testing of the muscular balance for distant vision with the Maddox rod.

11. With the full correction in place, the determination of the near point of accommodation and convergence.

12. The addition of the correction for near work, and the testing of the acuity with the near types, uniocularly and binocularly.

13. With the additional correction for near work, the estimation of the muscle balance for near vision with the Maddox wing test.

14. The trial frames are taken off, and, if it is indicated by the symptoms complained of and the results of 10, 11, 12, and 13, the testing of the vergence power by the Maddox prism verger.

15. If strabismus is present, the determination of the degree of binocular vision and the measurement of the angle of squint.

Digitized by Illinois College of Optometry Library

SECTION VI

SPECTACLES

CHAPTER XXIII

THE MAKING AND FITTING OF SPECTACLES

NOT only is some knowledge of the processes employed in the making and fitting of spectacles of interest from the ophthalmologist's point of view; it is also of the utmost importance, for many points arise in this connection which it is necessary for him to understand. The craft of the optician is a highly skilled one, by no means without its difficulties, and the surgeon can frequently help in overcoming these. The services of both are required in the optical treatment of the patient, the one no less essential than the other, and they should have the mutual knowledge to co-operate sympathetically.

The comfort of the patient, moreover, depends as much upon the optician as upon the surgeon. Small faults in the centring of the lenses or in the fitting of the frames may well result in the most unpleasant consequences, such as headache and eye-strain, diplopia and a tendency to squint; and the troubles of the patient may be perpetuated or even rendered worse than before although the prescription for the glasses may have been correct. Rightly or wrongly, if the glasses do not afford relief or should prove uncomfortable, it is the surgeon who is almost invariably blamed by the patient; his duty does not therefore end with an estimation of the optical error, and for his own protection he should make it a practice to verify the glasses after they are com-

Digitized by Illinois College of Optometry Library

pleted and before they are finally delivered to the patient. The ophthalmologist has no more valuable and essential asset than a reliable optician with whom to co-operate.

The Manufacture of Glasses

Historical.—The earliest origin of glasses is difficult to trace. The discovery of a convex lens of rock crystal by Layard in the ruins of Nimrud, near Nineveh, suggests that they may have been employed in some primitive manner some 3,000 years ago. The use to which this interesting relic was put is controversial, whether as a burning glass or as a magnifier: certainly Aristophanes, in the "Clouds," about 423 B.C., talks of the use of burning glasses, and Seneca, who lived at the time of Nero, at the beginning of the Christian era, refers to the use of magnifying glasses by engravers who practised their art upon minute precious stones. Indeed the detailed perfection and the delicate designs of the carving on ancient gems suggest that their use must have been known many years before Christ. The emerald which Nero himself carried to the games is well known; but it has given rise to question whether its purpose was ornamental or practical. Certainly his contemporary, Pliny the Elder (A.D. 23-79), in his sole surviving work, the Natural History, speaks of certain concave emeralds which had the curious property of "converging the vision" (*visum coligere*), for which reason they were never to be cut; and from Pliny we gather that Nero was near-sighted.

The scientific exploitation of optics for the aid of vision by the employment of magnifiers has been accredited to Ptolemy (A.D.150), but the treatise on optics which has been attributed to the great Alexandrian astronomer is probably spurious. Alhazen, an Arabian scientist of the 11th century, makes mention of them in his optical works, the translations of which into Latin, the "Opticae Thesaurus," probably disseminated what knowledge he possessed gradually throughout the monasteries of Europe. Such knowledge was, however, scrappy and questionable, and it was left to Roger Bacon (1214-94), of Oxford, to make a determined attempt to apply optical principles to the subject; while the first correct and complete theory of spectacles was not published until the time of Kepler (1571–1630), the astronomer of Würtemberg.

The first pair of convex glasses of which we have any record as being conceived on scientific principles, appears to have been made by Roger Bacon for the purpose of assistance in reading; he made them with his own hands, grinding them and polishing them out of some glass which he obtained from Belgium. Concave lenses were introduced shortly afterwards. For over five

Digitized by Illinois College of Optometry Library

hundred years any optical aberrations other than spherical were unsuspected, until in 1793, Thomas Young of London, the most versatile scientist whom England ever produced, published an account of his own asymmetrical refraction. Very shortly afterwards, in 1827, Airy, the professor of Astronomy at Cambridge, corrected such an astigmatic defect by means of a cylindrical lens.

Originally it would appear that a single glass was used held in the hand as an aid to vision. After the time of Bacon two lenses were employed, and the first picture showing as an incident such a combination affixed on a triangular frame is stated to have been painted at Treviso in 1352. The illuminations on a 15th century manuscript show such a pair of spectacles resting on the nose of a monk, while a picture of a Spanish Cardinal, painted in 1596, wherein a pair of glasses are held on to the ears by threads, marks a further stage in their evolution. Even in these early times their decorative value was considered. Henry Bowet, Archbishop of York (1407–21), possessed "Spectakeles de argento et de aurat" which were valued at 20 shillings; while August, the Elector of Saxony (1526–86), paid 12 guineas for a pair of Venetian spectacles in gold, and the famous painter, Albrecht Dürer (1521), was content with a pair which cost him 9½ farthings.

Like most of the arts and crafts, spectacle-making was largely confined in its earlier stages to the religious houses of Europe. In the 14th and 15th centuries the monks ground and polished their own lenses to assist them to read. In the succeeding centuries a considerable trade was made by merchants who vended them in basket-fulls, the purchaser choosing by a process of trial and error. The lenses were made by craftsmen, individually and by hand, the most illustrious of whom, the philosopher Baruch Spinoza (1632–77), eked out a lonely and precarious existence in lodgings at The Hague by selling them at the rate of a farthing apiece. Even made with such labour and sold at such a price, they paid him better than philosophy. At the present day, as in most of the arts and crafts, exact and scientifically constructed machinery has taken the place of the hands of the craftsman, and the optician has fallen into line with an age of mechanised mass-production.

Spectacle Lenses.—Spectacle lenses are now usually made of crown glass; the old-fashioned "pebbles" of quartz, which had the advantage of being hard and scratched only with difficulty, have fallen into disuse largely because of their greater expense, and their peculiar polarising properties. The glass commonly employed is a hard crown glass of refractive index 1·523, which, after annealing, has a high degree of transparency. Sometimes, when a glass of a

Digitized by Illinois College of Optometry Library

higher refractive index is wanted, as in the making of bi-focal or achromatic lenses, special types of crown glass or flint glass are used. It will be remembered that the refractive index of flint glass is 1·62.

The selected glass, after annealing, is made into rough "blanks," which are slabs of approximately the required thickness. This is subjected to "grinding," a process by which the surfaces are shaped by electrically driven tools of finely grained cast iron of appropriate curvature, the necessary abrasion being effected by a hard powder such as carborundum or emery. This is completed by "polishing," in which a covering of cloth or wax is substituted for the powder. The product forms the "uncut" lens, and the spheres and cylinders and toric forms employed in ordinary use are kept in stock in quantity in this state, their further treatment being dependent upon the requirements of the individual prescription.

When the prescription is supplied, and the size and shape of the lenses have been fixed, the optical centre and the axis of the cylinder, if one is present, are determined and marked. The uncut lens is then set in a "protractor" with the optical centre and the axis in the proper position, and the lens is "cut" to the proposed shape by a machine which engraves a deep line upon the glass. The glass is then broken off at this line by nippers, and subsequently "edged" by a rotating carborundum wheel, which grinds it to receive the frames into which it is now fitted.

Spectacle Frames.—The fitting of suitable spectacle frames is one of the optician's most delicate tasks, and upon his success in this much of the comfort and value of the glasses depend. He has several interests to meet which frequently are conflicting. Most important, from the optical point of view, there are certain criteria which are essential, and it is frequently a difficult matter to combine these successfully with the requirements of an asymmetrical face (a very variable quantity) and the patient's æsthetic demands (some

Digitized by Illinois College of Optometry Library

times a more variable quantity still). The essential requirements may be rapidly capitulated.

The frames must be rigid, strong, and light, and they must fit securely, yet lightly and easily, causing no irritation upon the points of the skin whereon they rest. They should hold both lenses firmly and constantly in a plane perpendicular to the direction of regard. Glasses for distance should therefore sit vertically, but since the eyes tend more frequently to be directed downwards than upwards, especially in tall people, they may be canted slightly downwards : an upward tilt is inadmissible for ordinary purposes. Glasses for reading should be slightly lowered, they should converge slightly, and they should be angled downwards at an angle from 15° to 20°, depending on the wearer's habit. In this way, when properly centred, the visual axis runs perpendicular to the plane of the glass ; otherwise, if there is a tilt in the lens, an astigmatic effect will be produced, the extent of which may be quite considerable (see p. 367). Moreover, the glasses should theoretically be held at a distance of 15·7 mm. in front of the cornea ; this, as has been noted already (p. 62), corresponds with the anterior principal focus of the eye, and at this distance the images formed on the retina will be of the same size as in emmetropia. Usually this distance is not adhered to, and the glasses are placed as near to the eyes as the lashes permit, at about 13 or 14 mm. distance. Finally, the lenses should be large enough to ensure a good visual field, a consideration which applies especially to children.

There are two main types of frames which are in common use : *spectacle frames* which are provided with side-pieces which find support upon the ears, and *nose-glasses*, the sole support of which is upon the bridge of the nose. It is obvious that the former form a much more adequate optical instrument than the latter. They are always to be preferred ; and they become essential in children, in labourers, in those engaged in strenuous sport and exertion, and in those in

Digitized by Illinois College of Optometry Library

whom a large refractive error, especially if it be astigmatic or associated with an anomaly of the muscle balance, necessitates a minutely adjusted and rigidly supported correcting lens.

Spectacle frames may be made of metal or tortoiseshell. Of the former, steel is more rigid than gold, and it is therefore more suitable for children and labourers. It may be useful to remember that in tropical countries where much moisture and perspiration may be expected, a non-rustable steel is advisable. Stainless steel is somewhat expensive; but ordinary steel may rust no matter how heavily it is nickelled.

Fig. 174.—Scholar's Spectacles.

Tortoiseshell suffers from the disadvantage of being brittle, but in those whose age and occupation admit of reasonable care, it has the advantage of rigidity combined with extreme lightness and comfort, due in great measure to the large and smooth bearing surface which it affords. The *bridge* should be moulded to suit the shape of the nose; it should have a broad surface so that the skin is not indented; and it should fit accurately, as otherwise the glasses will tend to fall forwards. In young children such an indentation is very difficult to avoid, and it is possible that the pressure may interfere with the full development of the nose. In such case, the so-called "scholar's spectacles" (Fig. 174) are very useful. These combine the principle of the spectacle frame with

Digitized by Illinois College of Optometry Library

that of the pince-nez, the front being supported by two pads fitting on the sides of the nose with a broad bearing surface ; the weight is thus carried by the sides of the nose, and at the same time adequate rigidity is ensured. The *side-pieces* should fit the temples lightly : a few cases of carcinoma have been recorded occurring over the site of prolonged irritation by ill-fitting glasses on the nose and temple. The *ear-pieces* should fit securely enough to prevent the glasses falling forward when stooping, but not sufficiently tightly

FIG. 175.—METHOD OF TYING ON SPECTACLES IN YOUNG CHILDREN.
A ribbon, broken by a small length of elastic, is used.

to chafe the skin. In children they should curl round the ear as fine spiral springs, to ensure a good grip ; in adults, especially when the glasses are not to be worn constantly, and when they are made of tortoiseshell, a partial curl facilitates their removal and adjustment ; and in women who are embarrassed with hair, straight sides may be almost essential. In very young children who wear glasses for the treatment of squint, ear-pieces of any kind may be inadvisable, and if the side-pieces terminate in a metal loop, a tape arranged over the head, as in Fig. 175, provides an effective and admirable means of fixation.

Nose-glasses are found useful by some on account of the

Digitized by Illinois College of Optometry Library

ease with which they are put on and taken off; by others they are favoured because of their appearance. The only pattern which is admissible is a rigid pince-nez which fits securely enough to ensure a constant adjustment; at the same time they should not injure the skin of the nose, nor cause epiphora by everting the puncta. They are fragile and frequently require attention, and care must be taken to see that they are properly adjusted. If they are placed obliquely so that one lens is nearer to the eye than the other, considerable optical errors are introduced, and if they are canted out of the perpendicular plane, a spherical lens becomes sphero-cylindrical, while the cylindrical element in an astigmatic lens becomes magnified. For this reason they should never be allowed in the case of large refractive errors, particularly astigmatic ones, or in conditions of heterophoria; and the use of less rigid frames, such as the old-fashioned "folders," should be excluded altogether except, perhaps, in simple presbyopia.

A *monocle*, the most difficult ornament to wear, is of little serious ophthalmological value, unless in cases of uniocular vision or to hide a deformity of one eye. As has already been mentioned, however, it is frequently of service to presbyopes who wish to refer rapidly to something, such as a railway time-table. Lorgnettes may serve a similar purpose on a shopping expedition, their easy access being preferable to the frequent adjustment and re-adjustment of a pair of spectacles. In cases of astigmatism, however, a monocle is rarely satisfactory since the adjustment of the glass is largely a matter of chance. It is usually most practicable to leave the cylinder out, or if that is impossible, the best that can be done is to avoid a circular glass, and employ one shaped to the contour of the face; it should be provided with a frame which makes it adjustable only in the one position, which carries it out of contact with the skin and the lashes, and which at the same time does not tend to produce an artificial ectropion.

Digitized by Illinois College of Optometry Library

Combinations of Glasses.—The inconvenience to the presbyope of changing his glasses to suit the distance at which he desires to work may be overcome by the use of glasses in which more than one lens is incorporated. The usual type is the *bifocal lens*, wherein the upper segment is adapted for distant vision and the lower one for near vision. These were first described by Benjamin Franklin in 1784, who suggested a two-piece or " split " glass, composed of two separate segments held together in a frame with a horizontal dividing

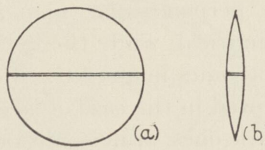


FIG. 176.—FRANKLIN BIFOCAL GLASSES.
(*a*) Front view, (*b*) section.

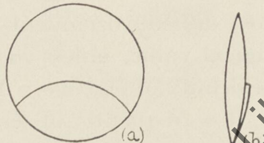


FIG. 177.—BIFOCAL LENS WITH SUPPLEMENTARY WAFER.
(*a*) Front view, (*b*) section.

line between them (Fig. 176). This suggestion was improved upon by the use of a supplementary lens or " wafer " which was cemented on to the surface of the main glass (Fig. 177). One surface of the wafer is worked to correspond with the spherical or cylindrical lens upon which it is to lie, while the other supplies the necessary additional curvature : thus if it were proposed to add an additional correction of + 3 D to a distance lens of + 2 D sphere, a wafer whose surfaces were ground to —2 D and + 5 D would be necessary. The cement employed is Canada balsam, which has the same refractive index as glass, but it suffers from the disadvantage that it

Digitized by Illinois College of Optometry Library

may dry and crystallise, or may soften and allow some degree of movement. Such a lens, however, has the advantages that it is easy to make, is inexpensive, is scarcely noticeable, is easily centred, and can be removed and altered when the presbyopic error increases. An improvement in stability and in appearance was introduced by Borsch in 1899, when the wafer was inserted into the middle of a lens which had been split, and was cemented there (Fig. 178). A further improvement depended upon the production of "invisible" bifocals by fusing the two elements together. In the

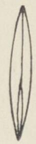


Fig. 178.—Bifocal Glass with Inserted Wafer

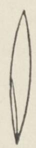


Fig. 179.—The Fused Bifocal Glass.

Kryptok lens a small depression is ground in the crown glass, and a "button" of flint glass, similarly polished and ground, is laid upon it, so that the increase in refractivity is obtained by virtue of the difference in refractive index. The two are clipped together and then heated in a furnace until they are fused (Fig. 179). The resulting lens has a good æsthetic appearance with no visible line of demarcation; but, inasmuch as the exacting conditions of refractivity, transparency, hardness, and expansion are difficult to fulfil, the optical effect is not invariably perfect. The last development has been the production of a compound lens in one solid piece, having two distinct curves ground upon its surface—the so-called

Digitized by Illinois College of Optometry Library

Luxe glass. The production of such a combination, however, if it is to be free from optical defects, is not without technical difficulties.

The essentials of a bifocal lens are : that it should be light ; that the dividing line should be inconspicuous or invisible, involving no sudden break ; that there should be sufficient field for each distance ; and that both elements should be correctly tilted and accurately centred to suit the visual axis as it is directed for the purposes for which the glasses are employed. No type of lens so far described satisfies all these conditions, and although the appearance of the later forms has greatly improved, their optical performance has not kept pace with their æsthetic qualities. For ordinary purposes, however, provided the refractive anomaly is not too large, they are quite permissible, and in many circumstances their utility makes their use amply worth while.

In the usual type used for distant vision and reading, the lower reading segment need only be small, so that the general field for vision can remain as large and unrestricted as possible ; as a rule the segments are unnecessarily big in such glasses. In some occupations, for example, in the case of artists, a large bifocal segment is desirable. But for ordinary purposes an ample field for reading is provided by an area on the page of 6 ins. long and 4 ins. broad, and if the book is held at a distance of 13 ins. from the eye, this will be covered by a segment which measures only 12·5 mm. by 9 mm. Great care should be taken in adjusting the optical centres of the combination (see p. 359). The line of demarcation, even although it is inconspicuous, should not interfere with distant vision : the diameter of the pupil is on the average 3 to 4 mm., and consequently the distance between the optical centre of the main lens and the upper edge of the segment (the " segment depth ") should be 2 to 3 mm.

The use of bifocals requires a considerable amount of

Digitized by Illinois College of Optometry Library

education, and some people take a long time to get accustomed to them. It is rarely advisable to make a stronger presbyopic addition than 2·5 or 3 dioptres in this form ; if a stronger reading glass is required, it usually causes annoyance and should be given as a separate pair of spectacles. The blurring of objects some feet away when looked at through the lower segment, indeed, may be a source of danger until the wearer has become accustomed to the optical effect, a circumstance which is particularly evident on such occasions as going downstairs or alighting from vehicles. The matter is more difficult for portly people, but not a few fail to accustom themselves to their new situation. The difficulty may be obviated in special cases by not allowing the

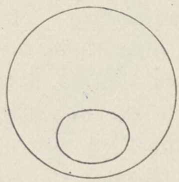


Fig. 180.—Bifocal Lens with Raised Segment.

segment to come to the bottom of the main glass, but leaving a narrow strip of the distance lens running underneath the segment (Fig. 180). A strip of only 2 to 3 mm. depth will give a view of 7 or 8 ins. breadth at a distance of 6 feet, which is sufficient for most purposes ; at the same time it will allow a segment of 9 mm. height to be used, and still leave 2 mm. of segment depth in a comparatively small spectacle lens of 28 mm. height.

Bifocal lenses for seeing at various distances in different occupations can be made in any variety. For some purposes *tri-focal lenses* are advocated : a combination such as + 1 D sphere for distance at the top of the glass, + 3 D in the middle, and + 4 D below may assist in allowing a presbyope with 1 D of hypermetropia to read at a large desk surrounded by a number of reference books, and yet to be able to see

Digitized by Illinois College of Optometry Library

across the room without a change of glasses. In the *multi-focal lenses*, introduced by Gowland of Montreal, in 1922, which go by the trade name of "Ultifo," the reading portion of the lens has a continuous variable curve, there being a gradual accretion of power from the periphery to the reading centre where the limit of the addition ordered is attained. There is thus embodied in the one lens powers for intermediate distances from infinity to the working distance, and the sharp jump from a distant to a near focus is eliminated, the multiple range thus counterbalancing the restriction of the range for close work.

As an alternative to bifocals, the additional correction for reading may be supplied as a separate pair of glasses placed in front of the distance ones ("hook-fronts"). It is more useful if these are "pantoscopic" with ◡ shaped lenses, so that it is easy to look over them for distant vision. To a simple presbyope glasses shaped in this way are extremely useful for reading, while the unaided eye looking over the glass is used for distance. A low myope will frequently read most comfortably through the converse arrangement, a kidney-shaped omission, corresponding in size to an ordinary bifocal segment, being cut from the lower half of a pair of rimless distance glasses.

Reversible glasses are sometimes recommended in cases where one eye only is available for vision. The nose-piece is made straight so that they can be fitted on upside-down, and if a distance lens is put in one eye and a reading lens in the other, the patient has merely to reverse the glasses to substitute the one for the other. It is almost impossible, however, for such glasses to fit correctly, and quite impossible for them to be accurately centred; and unfortunately the usual type of case wherein they are advised is that of aphakia, where, more than in any other instance, the powerful lenses usually necessary ought to be adjusted with minute precision. Such glasses should never be advised, least of all in these cases.

Digitized by Illinois College of Optometry Library

Spectacle Lenses

The Size and Shape of Lenses.—There is some confusion as to the standardisation of the size and shape of spectacle lenses. The notation suggested by the Optical Society is not widely adhered to: this differentiated varying shapes as round, round oval, long oval, and pantoscopic (an oval with a flattened top), and indicated the sizes by the circumferential measurement. The American notation indicates the shape of the oval by a number which denotes the difference in millimetres between the long and the short axes. In practice most opticians do not adhere to these, but adopt the much more suitable procedure of varying the size and

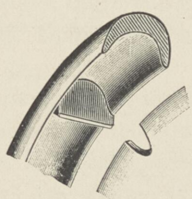


FIG. 181.—THE LENS LOCK, FOR USE IN THE FRAMES OF CIRCULAR CYLINDRICAL LENSES.

shape to conform to the requirements of the prescription and the configuration of the face. In children especially, large glasses providing a full field are best so that the wearer is not tempted to look over them. In the case of cylindrical lenses one advantage of an oval shape is that it prevents the lenses rotating should they become loose. If round lenses are used a "lens lock" of some form (Fig. 181), obviates the danger of a cylinder becoming misplaced in this manner in course of time.

The Form of Lenses.—The form into which the prescription is made is a more difficult and complicated matter. Theoretically it may be treated in several ways, and the lens may be symmetrical, asymmetrical, plano, periscopic, deep meniscus, or toroidal (see Fig. 182).

Digitized by Illinois College of Optometry Library

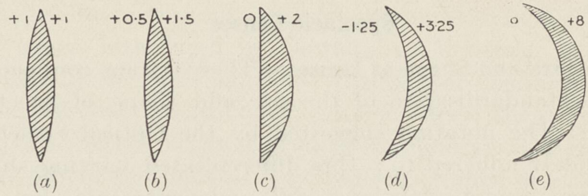


FIG. 182.—THE FORM OF LENSES.

A + 2·0 D sphere made up in five different forms :
(*a*) Symmetrical.
(*b*) Asymmetrical.
(*c*) Plano.
(*d*) Periscopic (to the base − 1·25).
(*e*) Deep meniscus (to the base − 6).

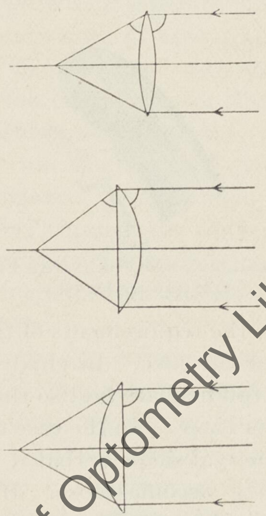


FIG. 183.—TO ILLUSTRATE THE BEST FORM OF LENS TO REDUCE THE EFFECTS OF SPHERICAL ABERRATION.

In the middle figure, when the greatest convex surface faces the incident light, the deviation produced at each surface of the lens is approximately equal.

In the *symmetrical form* each side is ground similarly, and a bi-convex or bi-concave lens results. In an *asymmetrical lens* the two surfaces are ground differently, and in the *plano*,

Digitized by Illinois College of Optometry Library

the whole of the curvature is placed upon the one side while the other remains plane. Thus a + 2 D sphere may be made up symmetrically with each curvature + 1 D, or asymmetrically with + 0·5 D and + 1·5 D, or as a plano-lens with + 2 D on one surface : in addition a sphere may be ground on one side and a cylinder on the other. The difference between these may not seem very material, but it is important to have as small a convexity facing the eye as possible. With any lens there is always a certain amount of spherical aberration depending on the degree of deviation of the rays of light, and this is reduced to a minimum when the deviation produced at each surface of the lens is the same. A consideration of Fig. 183 will show that this is attained when the convex surface faces the incident rays which are more nearly parallel than the rays which leave after refraction.

The remaining forms of lenses are based upon an attempt to eliminate as far as possible the optical errors inseparable from glasses. One of the main difficulties with spectacles, especially if the lenses are strong, is the lack of panoramic vision. In order to get the best optical result the eyes should remain fixed opposite the centre of the glass, and when the wearer wishes to see lateral objects clearly it is necessary for him to move his whole head in order to maintain the proper alignment, and enable him to use the glass and the eye as an optically centred system. When an eccentric portion of the lens is used so that the incident light is oblique, the lens acts as a sphero-cylinder and objects appear blurred. This effect is to some extent obviated if the lens is ground into the shape of a meniscus with the concave side facing the eye. The bending so disposes the peripheral parts that the rays of light passing through them become more nearly normal, and thus in addition to making the field greater and the peripheral definition better, the lens approaches the theoretical aplanatic and achromatic ideal. This is especially important where the peripheral parts of the glasses are

Digitized by Illinois College of Optometry Library

relied upon, as in games such as tennis, or when they are used frequently as in reading. In the latter case the strain of overcoming the prismatic effect during prolonged close study may be considerable. The range of the utility of these forms, however, is by no means unlimited, for the glass becomes impossibly heavy and cumbersome in the higher degrees of error ; moreover, the limits within which the effects of peripheral astigmatism can reasonably be reduced lie between — 20 D and + 7 D. Finally, such glasses are expensive.

One further small point deserves notice. Since the principal points of a diverging meniscus are one or two millimetres outside the glass on its concave (ocular) side, the meniscus acts as if it were a glass placed slightly closer to the eye, and hence need not be quite so strong as the correcting bi-concave lens. Similarly, since the principal points of a converging meniscus are situated in front of the glass, it also need not be so strong as a correcting bi-convex lens : but this effect in either case is so slight that it makes no practical difference in the prescription.

Huyghens (1629–95), the Dutch physicist who was responsible for the wave theory of light, first suggested that lenses should be corrected in some such manner as this, and proposed a ratio of surface curvatures as 6 : 1. The English physicist, Wollaston (1804), first prepared periscopic lenses, and the best forms were worked out by Ostwalt (1898), the French oculist, and later and in more detail by Percival, of Newcastle (1901). The subject is still engaging attention. Percival's recommendations for an eye whose centre of rotation is assumed to be 27 mm. behind the meniscus, and whose useful rotation is through a solid angle of 30 degrees, are given in Appendix V.

In practice it is impossible to manufacture an indefinite number of forms, and so a limited number of standard forms are relied upon in order to reduce the number of grinding tools. The standard surface is called the *base surface ;* the

Digitized by Illinois College of Optometry Library

other surface is called the *combining surface*, and it is specially ground to suit the individual prescription. The best practical base curves are :—

from + 7 D to 0	− 6 D next the eye.
from 0 to − 6 D	+ 6 D furthest from the eye.
from − 6 D to − 10 D	+ 1·25 D furthest from the eye.
from − 10 D to − 20 D	plane furthest from the eye.

A lens with a base of 6 D is called a *deep meniscus lens ;* one with a base of 1·25 is called a *periscopic lens.* For positive lenses a negative base curve is used, and for negative lenses a positive base curve, and in the fitting of the glasses the concave surface is always placed next the eye.

A *toric lens*, that is, a meniscus lens with a cylindrical curve

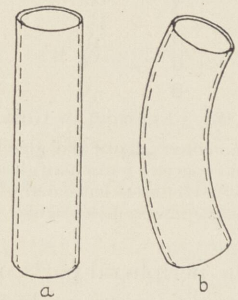


Fig. 184.—A Toric Curvature.
(*a*) A cylindrical and (*b*) a toric curvature.

ground on the spherical surface of one side, is made on the same principle. A " torus " is a term borrowed from architecture, and is descriptive of the curvature of an Ionic column ; in it the radius of curvature in one meridian is different from that of the one at right angles (Fig. 184). A walking stick may be exemplified as a cylinder ; when it is bent it assumes a toroidal form. A bicycle tyre is another familiar example ; if the tyre is 2 feet in diameter and 2 ins. in thickness, the radius of curvature of the horizontal meridian is 1 foot, while that of the vertical is 1 inch. The base curve

Digitized by Illinois College of Optometry Library

upon which toric lenses are constructed is almost invariably one of 6 D. A toric lens therefore consists of one spherical and one toric surface, the difference between the base curve and curvature of the principal meridian giving the cylindrical power of the lens.

It has been noted that beyond the limits of + 7 D and — 20 D meniscus-shaped glasses are no longer efficient. In extreme myopia and in aphakia, therefore, no single lens with spherical surfaces will eliminate oblique astigmatism. Gullstrand has suggested that the difficulty may be overcome

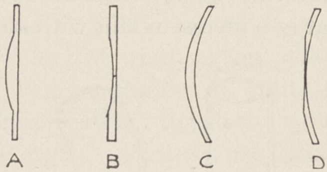


Fig. 185.—Lenticular Glasses.

A. Plano-convex lenticular glass.
B. Plano-concave lenticular glass.
C. Convex-meniscus lenticular glass.
D. Concave-meniscus lenticular glass.

in part by making the peripheral parts of a different curvature in the so-called *aspherical lenses*, but since in these cases peripheral vision is at best poor, the matter is as well neglected. Indeed, the greatest desideratum in such lenses is to keep down their weight and size, and for this purpose *lenticular glasses* are very useful (Fig. 185). In these, high-power lenses are ground only in the centre, and, although the field is thus reduced, the added comfort usually compensates for the loss. They may be improved by grinding them into a meniscus shape.

The Transposition of Lenses.—The process of changing a lens from one form to another equivalent form is called *transposition*. This may be considered under two heads—simple and toric transposition.

Digitized by Illinois College of Optometry Library

Simple transposition occupies itself largely with the alteration of the form of lenses in cases of astigmatism, and with the production of periscopic or meniscus lenses or of forms which produce some of their advantages. It is simply a matter of algebraic addition. In the transposition of cylinders two desiderata are always to be kept in view: an attempt should be made to keep the lenses as light as possible, and it is desirable to maintain the axes of the cylinders in the two eyes in approximately the same direction. In these manœuvres the only thing to remember is that while cylinders with their axes parallel are directly additive, two cylinders at right angles if of equal value are equivalent to a sphere, if of unequal value are equal to a sphere and a cylinder.

Thus + 2 D cyl. ax. 90° + 2 D. cyl. ax. 180° is equivalent to + 2 D sph.;

+ 2 D cyl. ax. 90° — 2 D cyl. ax. 180° is equivalent to a plane glass;

and + 2 D cyl. ax. 90° + 3 D cyl. ax. 180° is equivalent to + 2 D sph. + 1 D cyl. ax. 180°.

Further, any cylinder is equivalent to a sphere of the same power combined with a cylinder of opposite power with its axis perpendicular to that of the original cylinder.

Thus: + 2 D cyl. ax. 90° is equivalent to + 2 D sph. — 2 D cyl. ax. 180°.

Some examples will make the matter clear.

Thus if a refraction is — 0·5 D sph. — 1·0 D cyl. ax. 180° and it is desired to add + 1·5 D sph. as a presbyopic correction, the effect is gained by transposing to a simple + 1·0 D cyl. ax. 90°.

If + 2·5 D sph. is wanted as an addition, a suitable correction would be + 1·0 D sph. + 1·0 D cyl. ax. 90°.

Similarly an addition of + 2·0 D sph. to a — 4·0 D cyl. ax. 180° would take the form of — 2·0 D sph. + 4·0 D cyl. ax. 90°.

In some cases a cross-cylinder is preferable to a sphero-cylinder in that it is lighter and provides a wider field. Thus a + 3·0 D sph. — 4·0 D cyl. ax. 180° might well be converted into + 3·0 D cyl. ax. 90° — 1·0 D cyl. ax. 180°.

Again, if the refraction is given as

R.E. + 2·0 D cyl. ax. 90° — 1·0 cyl. ax. 180°,

Digitized by Illinois College of Optometry Library

L.E. — 3·0 cyl. ax. 180°,

the transposition

R.E. — 1·0 D sph. + 3·0 D cyl. ax. 90°, would be correct, but the presence of two cylinders in the two eyes at right angles would be borne with difficulty. The better transposition would therefore be

R.E. + 2 D sph. — 3 D cyl. ax. 180°.

Here, however, a thicker glass is involved, and for this reason the combination had best be left in the cross-cylinder form.

In the same manner the transposition of spheres into periscopic or deep meniscus forms is a question of simple algebraic addition. It is to be remembered that the given power is to be combined with a base curve of the opposite sign.

Thus a + 2 D sph. converted into periscopic form has curvatures of — 1·25 and + 3·25 D sph. A — 2 D sph. similarly converted has curvatures of + 1·25 and — 3·25 D sph.

In the same way a + 2 D sph. converted into a deep meniscus form has curvatures of — 6 and + 8 D sph., while the corresponding concave lens will be formed by + 6 and — 8 D sph.

Toric Transposition.—Toric transposition, although it appears a more complicated process, depends on the same principles and is as simple. The toric formula is written as a fraction, the numerator of which is a sphere, and the denominator comprises both the base curve and the cylinder necessary to give the required combination.

The steps in the transposition may be summarised thus :—

(*a*) Transpose the given prescription to one having a cylinder of the same sign as the base curve which is to be used.

(*b*) The spherical surface is given by subtracting the base power from the sphere in (*a*). This is written as the numerator of the fraction.

(*c*) Fix the cylindrical base curve with its axis at right angles to the cylinder in (*a*).

(*d*) Add to the base curve the cylinder in (*a*) with its axis at right angles to that of the base curve.

These (*c*) and (*d*) give the toric surface, and they form the denominator of the fraction of the formula.

An example will make this clear.

To transpose + 3 D sph. — 1 D cyl. ax. 90° to a toric formula to the base — 6;

(*a*) is already done;

to get the effect of — 3 D sph., the spherical surface must have

Digitized by Illinois College of Optometry Library

a curvature of + 9 D sph., *i.e.*, the base power subtracted from the original sphere, + 3 D − (− 6 D);
the base curve required for (*c*) is − 6 D cyl. ax. 180° ;
the other toric power to give a resultant of − 1 D cyl. ax. 90° is − 7 D cyl. ax. 90°, that is, − 6 D added to − 1 D ;
this gives a combination on the one surface of
− 6 D cyl. ax. 180° − 7 D cyl. ax. 90°,
or − 6 D sph. − 1 D cyl. ax. 90°.

The formula is written thus :

$$\frac{+\ 9{\cdot}0\text{ D sph.}}{-\ 6{\cdot}0\text{ D cyl. ax. }180^\circ\ /\ -\ 7{\cdot}0\text{ D cyl. ax. }90^\circ.}$$

In the same manner the transposition of + 5·0 D sph. − 2·0 D cyl. ax. 180° to the toric form to the base + 6 is accomplished thus.

Transposing the sign of the cylinder to correspond with that of the base, the prescription becomes :
+ 3·0 D sph. + 2·0 D cyl. ax. 90°.

A similar series of steps is now gone through, giving as a result :

$$\frac{-\ 3{\cdot}0\text{ D sph.}}{+\ 6{\cdot}0\text{ D cyl. ax. }180^\circ\ /\ +\ 8{\cdot}0\text{ D cyl. ax. }90^\circ.}$$

The Centring and Decentring of Lenses.—It is extremely important that when the glasses are fitted the optical centres should correspond with the visual axes of the patient's eyes, for it is only when this condition obtains that the rays of light will travel to his eyes without suffering deviation. It will be remembered that a lens may be considered as a combination of prisms, and that when light passes through any part of a lens outside of its optical centre, the effect is that of a prism with its base directed towards the thickest part of the lens.

In this connection two definitions must be borne in mind. The *optical centre* is the centre of the optical system formed by the lens, and all rays passing through it are undeviated. The *geometrical centre*, on the other hand, is the point in the middle of the lens, and is merely a relation of the placement of the lens in its frame. The two need not coincide, for, depending on the shape of the orbits and the asymmetry of the face, the lens may be displaced in any direction, provided the optical centre is kept in the correct position. For

Digitized by Illinois College of Optometry Library

cosmetic reasons it is usually advisable for the geometrical centre of the lens to be opposite the centre of the pupil.

In each case, therefore, the optical centres must be determined, and the glasses fitted accordingly. Further, especially when the glasses are of high power, the determination must be accurate. Thus when -10 D spheres are worn, for example, an error of only a millimetre in each eye will entail a total error of convergence of $1\ \Delta$. It is not suffi-

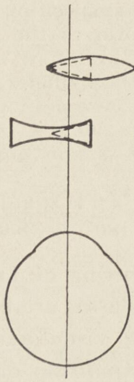


FIG. 186.—THE DECENTRING OF LENSES BY DISPLACEMENT OF THE ENTIRE GLASS.

If the eye figured is the right, decentring of a convex lens (v) outwards, or of a concave lens (c) inwards produces the action of a prism, base out.

cient to measure the interpupillary distance, as is often done, for, owing to the variability of the angle α, the visual axes may not coincide with the centres of the pupils ; moreover, each eye must be measured separately from the centre of the nose, for a face is rarely symmetrical. The most accurate method has already been described. It depends upon the determination of the point of light reflex on the cornea as the patient looks in a specified direction, and the measurement of this by means of cross wires in a trial frame whose excursion from the nose is marked in millimetres. The optical centres for distance glasses are thus found by asking

Digitized by Illinois College of Optometry Library

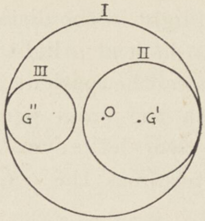


FIG. 187.—THE DECENTRING OF LENSES.

I, a large lens symmetrically centred, when O the optical centre and the geometrical centre coincide. From I may be cut II and III, in which the optical and geometrical centres do not coincide. They therefore act as prismospheres.

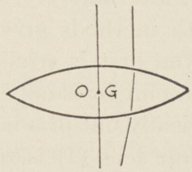


FIG. 188.—A NORMALLY CENTRED LENS AS FIG. 187 (I).

The optical centre (O) is at the geometrical centre (G).

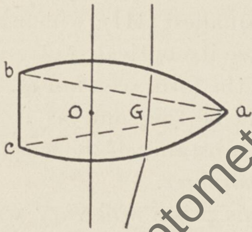


FIG. 189.—A DECENTRED LENS, AS IN FIG. 187 (II).

The optical centre (O) is placed eccentrically. A ray passing through the geometrical centre (G) will be deflected as if by a prism, *bac*.

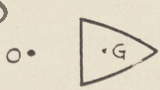


FIG. 190.—A DECENTRED LENS, AS IN FIG. 187 (III).

The optical centre (O) is outside of the lens altogether.

Digitized by Illinois College of Optometry Library

the patient to look at a light in the distance ; those for near vision by asking him to look at a light near at hand. The observer, seated opposite the patient, marks the position of the light reflex with the cross wire in the right eye, sighting it with his own left eye, and with his own right eye similarly determines the centre in the patient's left eye.

The Decentring of Lenses.—Lenses may be decentred in one of two ways. The optical centre and the geometrical centre may be allowed to coincide in the centre of the frame, and the frame may be displaced as a whole by lengthening or shortening the nose-piece. Or, alternatively, the lens may be displaced in its rim. Both methods give the same prismatic effect. The action of the first is seen in Fig. 186, but for cosmetic reasons, the second is usually to be preferred. In it lenses are cut eccentrically out of a larger one as is seen in Fig. 187. Here the large lens (I) is normally centred, for its optical and geometrical centres coincide (OG, Fig. 188). The smaller lens (II), however, will have its optical centre at O and its geometrical centre at G′, and will appear as in Fig. 189 ; while the smallest (III), which has its geometrical centre at G″, will have its optical centre at O outside of it altogether, assuming the form seen in Fig. 190. In each case the optical effect will be the same as if a prism had been interpolated into the substance of the lens (Fig. 187). Such a lens becomes a *prismosphere.*

The strength of this prism will vary with the amount of decentration and with the dioptric strength of the lens : it is found that there is a prismatic effect of 1 prism dioptre per 1 D for every 1 cm. of decentration which is effected. The amount of decentration in millimetres, therefore, equals $\frac{10\ N}{D}$, where N is the number of prism dioptres and D the strength of the lens.

Decentring a convex lens in any direction acts as if a prism were incorporated with its base towards the direction of

Digitized by Illinois College of Optometry Library

decentration, displacement of a concave lens has the opposite effect. Thus decentring a convex lens inwards or of a concave one outwards has the optical effect of a prism base in.

Where the prismatic effect required is oblique, the extent of the defect is usually calculated clinically as two components at right angles. Thus a patient may require a correction of 2 prism dioptres for a right hyperphoria, and of 3·5 for an exophoria. In such a case, as Percival pointed out, it is unsatisfactory to correct the vertical defect in one eye with a vertical prism and the lateral defect in the other with a horizontal one. The two com-

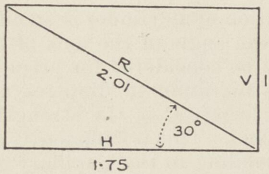


Fig. 191.—To Measure an Oblique Prismatic Effect.

H, the horizontal component for each eye = 1·75 units.
V, the vertical component for each eye = 1 unit.
R, the resultant = 2·01 units at an angle of 30° to the direction of H.

ponents should be resolved into one oblique deviation (Fig. 191), the effect being equally divided between the two eyes. Thus, in the present case, a horizontal line (H) of 1·75 cm. is drawn, a vertical one (V) of 1 cm., and the parallelogram is completed: the resultant (R) on measurement gives the result—a prismatic effect of 2·01 prism dioptres running upwards and outwards (for the right eye) at an angle of 30 degrees. If drawing to scale is objected to, the result can be found on calculation, for it is obvious that $R = \sqrt{H^2 - V^2}$, and the angle of direction $= \tan V/H$. In the present case, therefore, a correction of 2 prism dioptres pointing upwards and outwards at 30 degrees in the right eye and a similar correction downwards and outwards for the left eye would be prescribed. The glasses are therefore decentred in these directions by an amount in millimetres represented by 10 N / D. If the refractive error is 4 D, for example, the decentration would be $10 \times 2 / 4 = 5$ mm.

If the dioptric strengths in the two eyes are different, it follows that the amount of decentration must be different in each. If the lens be cylindrical, the amount depends upon the direction of the axis. As far as the cylinder is concerned,

Digitized by Illinois College of Optometry Library

any decentration in the direction of its axis has no optical effect ; any decentration in the direction perpendicular to its axis has the same effect as in the case of a sphere. Thus a combination of + 2 D sph. + 3 D cyl. ax. 90°, if decentred upwards, acts as a + 2 D sphere, if decentred inwards or outwards, as a + 5 D sphere. If, however, the cylinders are oblique, or if an oblique decentration is required in a vertical or horizontal cylinder, the effect is more complicated.

Every oblique section of a cylinder is an ellipse, and, as Percival has shown, if θ be the angle of the axis of the cylinder with the meridian which is to be considered for prismatic effect, the power of the lens in that meridian in dioptres is represented by the expression $C \sin^2 \theta$, where C is the strength of the cylinder (at right angles to its axis). This is sufficiently accurate for the small central area corresponding to the pupillary aperture. The power of a cylindrical lens, for example, of — 4 D at an angle of 150°, would be

$-4 \sin^2 150°$ in the horizontal meridian,
and $-4 \sin^2 (\theta - 90)$, or $-4 \cos^2 \theta$, *i.e.*, $-4 \cos^2 150°$ in the vertical meridian.

$-4 \sin^2 150° = -4 (\frac{1}{2})^2 = -1$ D,

and $-4 \cos^2 150° = -4\left(\sqrt{\frac{3}{2}}\right)^2 = -3$ D.

This can be simply verified : if a lens measure be placed at 30° with the plane axis of a 4 D cylinder, the reading is 1 ; if it be placed at 60° the reading is 3. The decentration vertically or horizontally is then calculated on this basis in the manner already described.

Decentration is thus an alternative method to incorporating a prism in a lens or grinding a lens on to a prism as basis. It has the advantage of being considerably easier for the optician and considerably cheaper for the patient, since a prismatic lens has to be specially ground. The process, however, has its limits, for it necessitates a proportionate increase in weight : it is obvious, for example, that the lens of Fig. 189 is heavier than that of Fig. 188. In addition, a powerful prism is associated with chromatic and distortion effects. In general, therefore, decentration should be effected

Digitized by Illinois College of Optometry Library

by displacing the entire glass as much as can be done without interfering with the field of vision or with the cosmetic appearance, and the remainder should be obtained by displacing the lens in the frame. On the average a decentration of much more than 4 to 6 mm. will be found to be inconvenient, and it will be found better to make up the remainder (or the whole) of the prismatic effect by grinding the appropriate curvatures on a prism.

Decentring is required for three purposes :—

1. To adapt a pair of glasses to an asymmetrical face, in

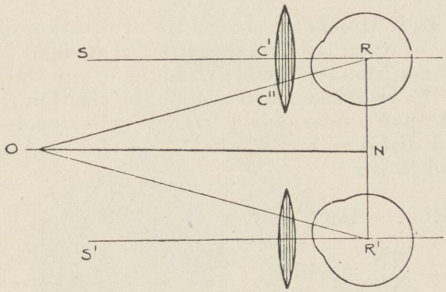


Fig. 192.—Decentration Inwards for Reading.

RN is the distance of the centre of rotation of the eye from the nose. RS, the visual axes directed straight forwards, and O, the near object looked at. The glass in front of the eye must be decentred from C′ to C″.

order to secure a cosmetic result. If one eye differs in its position from the other, it usually looks better to keep the glasses symmetrical, and to decentre the lenses so that their optical centres are cut by the visual axes. Such a process, of course, gives no prismatic effect, and if one is desired, an additional amount of decentring must be arranged for, the addition being made algebraicly.

2. Decentring for near work. For near work the visual axes are converged and directed downwards, and the changed positions of the optical centres when the eyes are directed towards an object at any distance may be found clinically by the method already described (see p. 262). On the average

Digitized by Illinois College of Optometry Library

it will be found that the centres for reading should be about 6·5 mm. below the horizontal, but the distance will depend on the habit of the individual. As a rule, when reading, the head is lowered about 20° to 30° while the visual axes are further depressed by a downward rotation of the eyes through an angle of approximately 15°. It is to allow for this angle that the optical centres ought to be lowered. The amount of convergence necessary will vary with the inter-pupillary distance and the distance from the eye at which the glasses are worn : an average is 2·5 mm. from the mid line. It may be calculated from the following formula.

In Fig. 192, if R denotes the centre of rotation of the eye, RS the visual axes when the eyes are directed straight forwards, and RN the distance from the visual axis of the eye to the central point of the nose, the visual axes will assume the position RO when they are directed upon a near object (O). C′ will denote the position of a glass for distance, and C″ that of one for reading. C′C″ can be calculated thus :—

$$\frac{RN}{NO} = \tan RON = \tan C'RC'' = \frac{C'C''}{C'R}.$$

Hence $C'C'' = \dfrac{RN}{NO} \times C'R.$

RN is measured : suppose it is 30 mm.
NO = the distance of the object from the glass + the distance of the glass from the centre of rotation of the eye, say 300 mm. + 25 mm. = 325 mm. ;
and C′R is also 25 mm.

$C'C''$ therefore $= \dfrac{30}{325} \times 25 = 2{\cdot}3$ mm. If this decentration is not done, the visual axis, RO, cutting the periphery of the lens, would be subjected to a prismatic effect, and any reading would become blurred.

In the making of bifocals the centring frequently gives rise to difficulty, and this is often the reason why these glasses are so often unsatisfactory, particularly in anisometropes.

For example, let us suppose that a refraction for distance is R.E. + 3 D sph., L.E. + 6 D sph., and that it is proposed to add a reading correction of + 3 D sph. If the segments are placed symmetrically, the left lens, having a much higher dioptric power than the right, would produce a higher prismatic displacement.

Digitized by Illinois College of Optometry Library

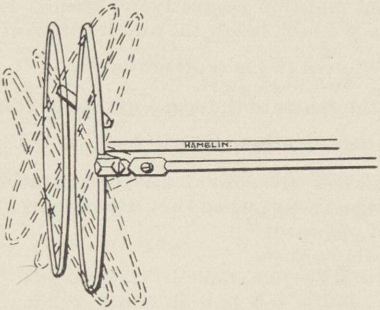


Fig. 193.—Sports Glasses Provided with an Adjustable Angle of Tilt.

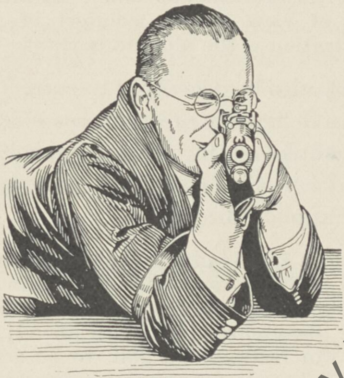


Fig. 194.—The Line of Vision in Shooting.

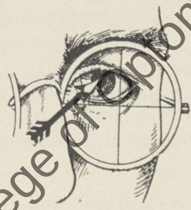


Fig. 195.—The Centring of Shooting Glasses (Hamblin).

Allowance must therefore be made for this. From a practica point of view a suitable correction can be made from the following simple formula suggested by Percival.

If D and d represent the dioptric strength of the distant glass

Digitized by Illinois College of Optometry Library

and the reading addition respectively, then if the centre of the segment is to be 6·5 mm. below the mid-horizontal line, the vertical decentration required (V) is represented by $\frac{D}{d} \times 6{\cdot}5$.

Similarly, if the centre of the segment is to be converged 2·5 mm., the horizontal decentration (H) will be $\frac{D}{d} \times 2{\cdot}5$.

When the glasses are convex the decentration is downwards and inwards respectively; when they are concave, the decentration is upwards and outwards.

Thus in the above case,

$V\,(R.E.) = 3/3 \times 6{\cdot}5$, and $H = 3/3 \times 2{\cdot}5$.

$V\,(L.E.) = 6/3 \times 6{\cdot}5$, and $H = 6/3 \times 2{\cdot}5$.

Hence the segment for the right eye is decentred 6·5 mm. downwards, and 2.5 mm. inwards, while that for the left eye must be decentred 13 mm. downwards and 5 mm. inwards. Of these two, from the point of view of the comfort of the patient, the horizontal decentration is the more important.

3. Glasses may also be decentred to correct a heterophoria, or to overcome a deficiency or an excess of convergence, the process being employed in place of incorporating prisms (see Chapter XVI.). To accomplish this the principles outlined above are applied directly.

In some cases it is an advantage that glasses should be centred in unusual ways. This is especially evident in various forms of sport. A simple way of producing the same effect for some purposes is to have glasses provided with an adjustable degree of tilt (Fig. 193). For instance, in golf, to be accurately centred, the glasses should be tilted downwards for putting or driving; or again, in playing a long shot in billiards they require to be tilted upwards. Similarly in target shooting, the line of vision is directed through the upper and inner quadrant of the lens (Fig. 194), and for accuracy in aiming the optical centres should be situated here in the glass of the sighting eye (Fig. 195). If this is not done a considerable prismatic effect is introduced, and the object in each example (the golf ball, the billiard ball, or the target) will be displaced as is illustrated in Fig. 8, frequently with deplorable results.

Orthoscopic Lenses.—Orthoscopic spectacles are prismospheres which relieve exactly the same amount of accommodation and convergence; thus if glasses were required of + 2 D sph. for close work, prismospheres combining + 2 D sph. with prisms (bases in) producing 2-metre angles of

Digitized by Illinois College of Optometry Library

convergence would be given. The same effect is obtained if both lenses are cut from one large lens so that the two have a common optical centre. Scheffler originally proposed these lenses for presbyopes, but since the amplitude of convergence remains unimpaired while accommodation diminishes with age, their use in these cases as a routine is unsound. They are frequently found useful, however, in non-presbyopic persons who wish to increase their visual acuity for very fine work by increasing the size of the image by bringing their work close up to the eyes. If simple magnifying lenses are provided binocularly for this purpose, accommodation is relieved while convergence is not, and the strain thus thrown upon convergence becomes intolerable unless prisms are used. Such glasses are found useful in trades which demand a high degree of visual acuity, such as in those who wind the filaments in electric light bulbs, or in hose-linkers, and they may well be of considerable service to the operating ophthalmic surgeon.

Discomforts arising through Glasses

When glasses have been prescribed discomfort may arise from one of three causes : the prescription may not have been correct ; the glasses may have been improperly fitted ; or some optical anomaly may exist which may, to greater or less extent, be inseparable from the type of lenses which have been found necessary. In the first case, the responsibility lies with the surgeon ; to avoid the second, he should make it a practice to verify the glasses ; and in the third case, several points may be suggested which may save considerable discomfort.

The Verification of Glasses.—The verification of glasses includes the checking of the strength of the lenses and the fitting of the frames : the importance of the first is obvious, but the amount of discomfort which may arise from the second cause is too frequently forgotten.

Digitized by Illinois College of Optometry Library

The strength of a lens may be measured by special instruments, such as the Geneva lens measure, or, more exactly, by the method of neutralisation.

The *Geneva lens measure* (Fig. 196) is provided with two fixed supports on either side and a moveable one placed centrally, so that, when placed upon a lens, the moveable leg is deflected by an amount depending on the curvature of the surface. The deflection is recorded after the manner of an aneroid barometer on a scale marked in dioptres, and thus the dioptric value of the lens in any meridian may be

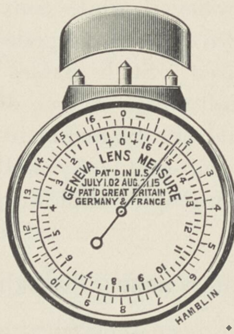


Fig. 196.—The Geneva Lens Measure.

read off directly. The instrument thus gives an indication of the form (toric or otherwise) in which a lens has been made up. It is graduated for glass of a refractive index of 1·523 (ordinary crown glass), so that if any other glass is employed a correcting factor must be applied. Its accuracy should be checked periodically by standing it upon a plane surface, and adjusting it to the zero of the scale by screwing one of the stationary legs. More complicated instruments are supplied which read off the dioptric power of a lens, and record the strength of a cylinder together with the angle of its axis, but as a rule these will not be required by the practising ophthalmologist.

The *method of neutralisation* (see p. 49) is the most

Digitized by Illinois College of Optometry Library

practicable method to employ. The most accurate procedure to adopt is to look through the lens at a cross drawn on a piece of cardboard (Fig. 197, I). If the cross appears skewed by a scissors movement as the lens is rotated round (II), it is rotated until there is no deformation of the cross-lines (III). The lens is now moved in a direction parallel to one of the lines, say up and down ; when a deviation of the horizontal

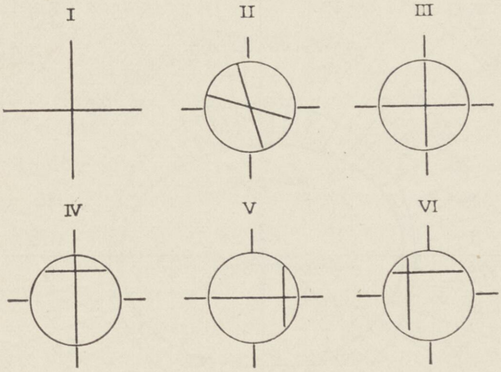


Fig. 197.—The Neutralisation of Lenses.

I. A cross which serves as an object mark.
II. Scissors movement on rotation.
III. Appearance when centred and lines are in direction of axes.
IV. Neutralisation of horizontal meridian.
V. Neutralisation of vertical meridian.
VI. Prismatic displacement.

line will be noticed (IV) ; if the curvature of this meridian is convex, the apparent movement will be in a direction opposite to that of the lens, if concave, it will appear to be in the same direction as that of the lens. Lenses from the trial case of opposite sign and gradually increasing strength are now held up in combination with the lens under examination until this movement is exactly neutralised : this gives the dioptric value in this meridian. The lens is then moved in the meridian at right angles : if no deviation of the line occurs, it has been neutralised in this meridian also and is a sphere ; if one does

Digitized by Illinois College of Optometry Library

appear (V), it is neutralised in exactly the same way by placing cylinders with their axes in the appropriate direction : this gives the value of the cylindrical element. It is well to mark these meridians with glass pencil : the point at which they meet is the optical centre. The lens is then laid upon a

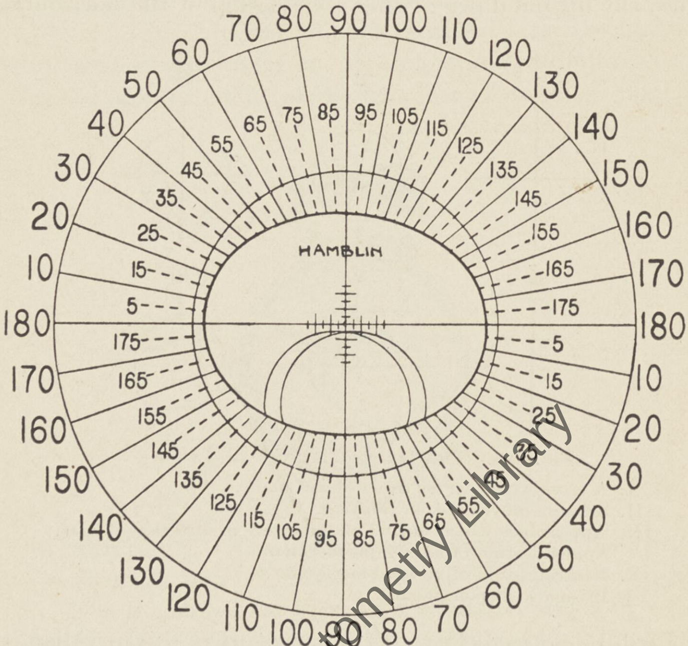


Fig. 198.—The Lens Protractor.

protractor (Fig. 198) with the horizontal diameter along the zero line and the axis of the cylinder as marked is read off. The geometrical centre can be found by measurement, and any decentring immediately verified. Finally, a prism may be present. When the exact neutralising lenses are combined with the glass, the combination should ordinarily act as a glass plate, and on movement in any direction the cross should appear unaltered. If, however, a prism is pre-

Digitized by Illinois College of Optometry Library

sent, on moving the lens there is no relative movement of the arms of the cross, but a displacement of the entire cross in one direction (VI). Prisms should now be combined with the lens until this effect also is neutralised. During the process of neutralisation the lenses should be held with their optical centres opposite each other, and they should be approximated as closely as possible, for any degree of separation introduces an error. Where some degree of separation does exist, a condition which must obtain to a certain extent, a convex lens appears slightly stronger than it actually is, so that when strong lenses have to be employed in the process of neutralisation, the convex element predominates in the combination. This, of course, has to be allowed for.

When the lenses are verified, their fitting should be examined. The distance of the visual axis of *each* eye from the mid line is to be measured and the centring of each lens checked for distance, and for near work if necessary. Small errors here, particularly in the segments of bifocals, are productive of much discomfort ; it is most marked if convex glasses are placed too far in or concave one's too far out, so that an error of divergence is caused.

The tilting of the glasses should then be examined ; they should lie as nearly as possible perpendicular to the visual axis so that the incident light falls upon them normally. If any tilt is introduced the spherical power is slightly increased and a cylindrical effect is added. When the lenses are of high power these effects may be considerable. The

Obliquity.	Spherical value.	Cylindrical value.
10°	10·101 D	0·314 D
15°	10·228 D	0·734 D
20°	10·409 D	1·379 D
25°	10·648 D	2·315 D
30°	10·948 D	3·349 D
35°	11·314 D	5·547 D

Digitized by Illinois College of Optometry Library

table on p. 367, taken from Percival, shows the error introduced by tilting a 10 D sphere through various angles when the index of refraction of the glass is 1·523.

This astigmatic effect produced by the refraction of a pencil of light through an inclined lens may be taken advantage of by patients who require a horizontal cylinder and who cannot afford sphero-cylinders. Thus it may be useful in aphakic patients who frequently have a cylinder in the horizontal axis, which must be decreased in strength after some time, a change which can be effected by merely straightening the glasses. Another advantage of the method is that the lenses are lighter without the cylindrical addition.

If the glass is not 10 D sphere, but some other value, the figures in Percival's table are multiplied by the tenth part of the power of the glass: thus if the strength of the sphere is 9 D or 11 D, they are multiplied by 0·9 or 1·1. Hence if an effect of + 11·5 D sph. + 1·5 D cyl. ax. 180° is required,

$$\text{since } 1{\cdot}1 \times 10{\cdot}409 = 11{\cdot}5$$
$$\text{and } 1{\cdot}1 \times 1{\cdot}379 = 1{\cdot}5$$

the effect can be obtained by prescribing + 11 D sphere tilted downwards at 20°.

Similarly, if a high myope of − 20 D sph. − 2·5 D cyl. ax. 180° complains of the weight or expense of his glasses, he can be treated in the same way.

$$\text{Thus } 1{\cdot}9 \times 10{\cdot}409 = 19{\cdot}78$$
$$\text{and } 1{\cdot}9 \times 1{\cdot}379 = 2{\cdot}62.$$

He is therefore given − 19·75 D sph. inclined at 20°.

The distance of glasses from the eye is important: theoretically this should be 15·7 mm., and as close an approximation to this as is possible should be aimed at. If they are placed farther from the eye than this, a convex lens acts as a stronger lens, and a concave lens as a weaker one, and if they are nearer, the opposite effect is produced; with strong lenses the error thus introduced may be considerable, amounting to one or two dioptres. This question of distance holds good for both surfaces of the lens, so that when the lenses are thick a further source of error arises: the equivalent power of a thick lens is slightly smaller than that of an ideal thin lens.

Digitized by Illinois College of Optometry Library

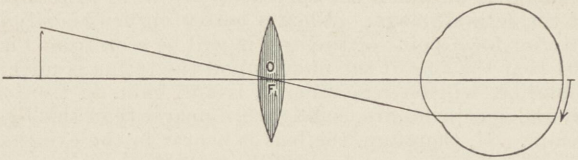


FIG. 199.

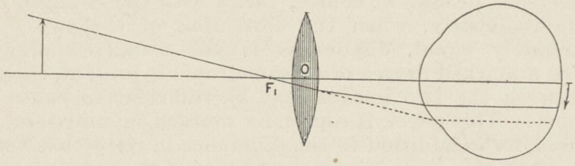


FIG. 200.

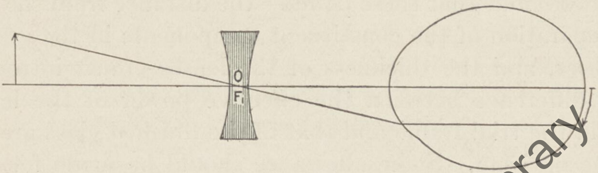


FIG. 201.

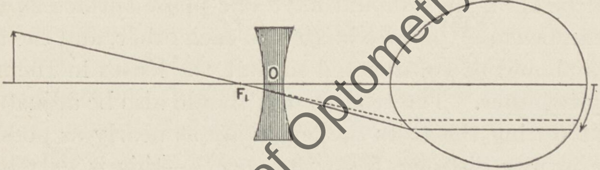


FIG. 202.

FIGS. 199, 200, 201 AND 202.—TO SHOW THE VARIATION OF SIZE IN THE RETINAL IMAGE WITH DIFFERENT POSITIONS OF THE LENS.

When the centre of the lens (O) is at the anterior principal focus (F) the size of the image (indicated by the arrow) is unchanged (Figs. 199 and 201).

When the centre of the lens (O) is nearer to the eye than the anterior principal focus (F), the image in the case of a convex lens is reduced (Fig. 200), and that with a concave lens increased (Fig. 202).

Digitized by Illinois College of Optometry Library

The distance at which the spectacles are worn also affects the size of the retinal image. When a correcting lens is situated at the anterior focal point of the eye, it will be seen from Figs. 199 and 201 that the size of the image upon the retina is unchanged. This point, it will be remembered, is 15·7 mm. in front of the cornea, and spectacles are usually worn nearer than this by about 1 or 2 mm. If, therefore, the lens is nearer to the eye than this point, in the case of a convex lens the retinal image is diminished (Fig. 201), and in the cases of a concave lens, it is increased (Fig. 202). If the lens is further away, the opposite effect is produced. The difference in size, of course, varies with the strength of the lens. Consequently, when the correction of the two eyes is approximately equal, discomfort is not usually experienced, but when a marked degree of anisometropia is present, the difference between the two images may be sufficient to cause some annoyance. This effect is especially marked in unilateral cases of aphakia, for in addition to the difference in refraction between the two eyes, the anterior principal focus of the aphakic eye has been altered and now lies much farther out (see p. 146).

It is obvious that these points—the distance from the eye, the separation of the constituent components in the system of lenses, and the thickness of the lenses—must introduce some difference between the effective power of the lenses used in the trial frame and that of the finished glass ground by the optician. Some allowance should be made for this where the error is high ; and great pains should be taken that it is minimised as much as possible. Thus the trial lenses should be thin, they should have one plane surface so that they can be closely approximated to each other, and the trial frames should be constructed so that the lenses in them lie closely together. The trial frames should also be adjustable so that during the tests the lenses are as nearly as possible at the proper distance from the cornea—this is extremely important. Finally, it goes without saying that in the trial frame they should be carefully centred.

In addition to these sources of error, the glasses may give rise to discomfort even although they have been correctly dispensed and accurately fitted. We have already dealt with the various optical defects inseparable from all lenses (see p. 63), and particularly when glasses of high power are

Digitized by Illinois College of Optometry Library

used, these may make themselves felt sufficiently to give rise to considerable annoyance. One of the most prolific sources of trouble is the distortion of the image due to peripheral magnification. This is positive in convex lenses and negative in concave ones when the peripheral field is compared with the central, so that long straight lines become curved after the manner of Fig. 203, when viewed through the spectacles. In this way objects appear to be mis-shapen when looked at, and since the curvature increases as the peripheral parts of the spectacles are used, they seem to move when the head

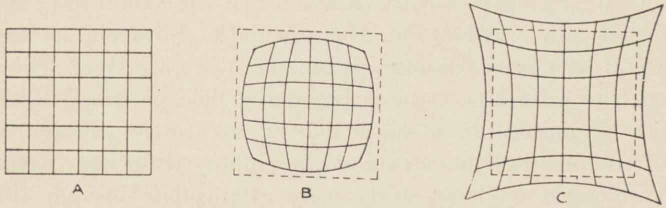


Fig. 203.—Distortion by Lenses.

A, Object viewed through a plane glass.
B, The same object viewed through a concave lens.
C, The same object viewed through a convex lens.
The dotted line in B and C indicates the real size.

is turned. This may prove extremely annoying to the wearer, but it is an unavoidable fault the effect of which can be minimised only with use.

The distortion effects of cylinders are also important, and these vary with the relation of the direction of the axes. Where the axes are parallel and each eye is subjected to the same deviation, the effect is minimised. When any difference exists, the lenses must be very accurately centred, otherwise there will be a tendency towards distortion effects wherein rectangles appear as rhomboids: this, of course, occurs unavoidably when the periphery of the lenses is used. Where the difference in the direction of the cylinders is small (about 10° or 20°), the annoyance may wear off in

Digitized by Illinois College of Optometry Library

time; but where the difference in the direction of the cylinders is greater than this amount, the optical effect may give rise to real trouble. For this reason different glasses should always be prescribed for reading and distance, and, if necessary, for work, each being accurately centred for the purpose for which they are intended. It is to be noted also that the nearer the glasses are placed to the eye, the less these distortion effects are evident.

The same considerations apply to cases of anisometropia even when the error is spherical. On looking towards the periphery of two lenses of different power, say 1 D and 5 D, the prismatic effect is very different: if the visual axes are directed downwards 1 cm. the prismatic deviation in one eye will be 1 prism dioptre and in the other 5. Here again, when the refractive error is large, the field of comfortable vision is limited to a small central area, and differently centred and tilted glasses should be employed for near work. If prolonged work or study were attempted through the peripheral parts of the distance glasses in such a case, the difference in the prismatic effect would be intolerable.

As it is, people with high errors (aphakics and high myopes) are constantly troubled on those occasions when they must look eccentrically through their glasses, as for example, going downstairs. These annoyances are unavoidable and can only be diminished by custom. The corrected eye has three elements in its optical system: the glass, the cornea, and the crystalline lens. It is quite impossible to combine the three into a perfect and harmoniously working optical system, and when the refractive error is large and the glasses are strong, a certain amount of discomfort must be expected and must be tolerated.

Special Types of Glasses

Special types of glasses are employed from time to time for two main purposes; (1) as protective glasses, either to

Digitized by Illinois College of Optometry Library

protect the eye against some form of radiation or against mechanical injury, and (2) in special combinations to obtain an optical effect which could not be attained by a simple lens.

Protective Glasses.—Protective glasses may be used to protect the eye from some radiation by diminishing the total intensity of the light, or by cutting off a noxious portion of the spectrum, either the long heat rays (the infra-red), or the luminous (visible) rays, or the short chemically active (ultra-violet) rays. Such glasses are not necessarily used for optical purposes at all, and therefore they will be dealt with shortly here. A very large number of various types of glasses have been placed upon the market from time to time, and each has been exploited more than the other: most of them are commercial propositions rather than scientific productions, and few of them have anything in particular to recommend them.

They may act in one of two ways: the unwanted rays may either be *absorbed* or *reflected*. The majority belong to the first class, and are prepared by combining the glass with some chemical substance or substances with special absorbing properties. The ingredients most frequently incorporated in the glass are metals, as copper, gold, manganese, iron, cobalt, chromium, and others. It can be reasonably understood that as a general rule the manufacturers are reluctant to liberate data concerning the chemical constitution of their products, but in the majority of cases the mixtures appear to be somewhat indefinite, and their spectral analyses and transmission intensities give very discordant results.

Practically all these substances are coloured, and the glasses are therefore tinted; consequently they suffer from the disadvantage that the depth of the tint varies with the thickness of the lens. Thus a convex lens will be deeply tinted in the centre, while a concave one, on the other hand, will have its maximum intensity in the periphery, the central part, which is really the essential part, remaining more or less clear.

Digitized by Illinois College of Optometry Library

This may be obviated by making the lens of clear glass in the first place, and then dipping it in a special gelatine solution containing the necessary chemicals so that the absorbent is distributed equally, a principle which was introduced by Menkel, in Germany, and which has been adopted in making the " unbral " glasses of Zeiss. A glass recently introduced, called " Soft-lite " glass, embodies this principle, and has the advantage of cutting down the spectrum non-selectively. The small and clear images formed by strong concave lenses make a tinted glass of this nature very suitable for high myopes. A further additional advantage in these cases is to have the lenses as thin as possible. A considerable thickness is saved if flint glass be used instead of the usual crown glass, owing to the higher refractive index of the former. A tinted glass of this nature is used for " Soft-lite Thin-lite " lenses. A different method of procedure is to grind a plano-convex or plano-concave lens, and cement a slab of a chemically tinted glass on to it, or to insert such a slab into the substance of a split lens. These, however, suffer from the disadvantage of size and weight. Such glasses are called *isochromatic glasses.*

Alternatively, instead of absorbing the unwanted rays by chemical substances, they may be *reflected* on a mirror surface, as was proposed by Schreiner, of America. Such surfaces are formed by layers of a metal, such as gold or silver or platinum, of such extreme thinness (of the order of 10 to 15 $\mu\mu$) that they remain to a large extent transparent to luminous rays. The delicate lamella is then protected by incorporating it with the substance of a split lens, where it is cemented or fused.

For cutting off the *luminous rays* and thus lessening the discomforts of glare, various forms of tinted glasses are used : they are thus of service in places where the sun is strong, or where its intensity is increased by the reflection of light from a large mirror surface as the sea, the plains of the tropics, the desert, or a snow-field. In ordinary

Digitized by Illinois College of Optometry Library

illumination, however, they are quite unnecessary for the healthy eye, and the frequency with which they are employed in temperate climates depends largely upon fashion and erroneous ideas of the action of light upon the eye. Many neurasthenics and mentally abnormal people demand such tinted glasses; but, while such folk have to be humoured to a certain extent on occasion, the use of these glasses should be deprecated in general, for in addition to accentuating the wearer's abnormality, their habitual use not only induces a fixed dislike of light of an intensity which is perfectly harmless, but may result in a real inability to endure it unaided without suffering all the discomforts of photophobia.

In addition to diminishing the intensity of light in the normal eye, tinted glasses may be of service in protecting the abnormal or diseased eye from an excess of light. They are thus useful in cases where prolonged dilatation of the pupil by atropine is necessary, in albinos who are provided with an inadequate supply of pigment to absorb an excess of scattered light, and in cases of cataract extraction where the removal of an opaque lens has subjected the eye to unusual conditions. The strength of the converging glasses usually necessary in these latter cases provides an additional reason for employment of some tint, since spheres of high power tend to concentrate the light after the manner of a burning glass. In the early stages of cataract there is a considerable amount of evidence that an excessive amount of light is harmful, and in any case it is usually annoying to the patient; in these cases also some protection may be advisible. In many diseases of the retina and choroid also, it is well that the light entering the eye should be cut down to a minimum. The damping down of the functional activity of a tissue is the first step towards giving it the rest which a pathological condition frequently requires.

In most of these cases, and in all of them where the eye itself is healthy, the ideal glass is that which cuts off as little of the light as is necessary, and which cuts it off through-

Digitized by Illinois College of Optometry Library

out the spectrum uniformly, so that colour schemes are interfered with as little as possible. In this way the sombre and depressing effect which all tinted glasses tend to produce is reduced to a minimum, and the appearance of things is changed as little as is necessary. The cheapest glass, which is also of very general utility, is the ordinary *smoke glass*, which, containing a variety of chemical colouring ingredients is available in four degrees of shade (I, II, III and IV). These, however, have a somewhat depressing effect, and interfere more with the colouring of objects than *Fieuzal* which is equally effective. This is available in five degrees of intensity (I, II, III, IV and V), but unfortunately, the samples are not reliably standardised. Probably the most efficient glass is one of those whose chemical formulæ were worked out by Sir William Crookes, which, in addition to diminishing the intensity of the luminous rays, cut off the visually useless ultra-violet rays.

The commercial *Crookes's glass* is obtainable in two forms, each of which is graded: Crookes's A (I and II), which affords a slight general shade without materially lowering or altering the colour values, and Crookes's B (I and II), which, being provided with a smoke tint, cuts down the intensity of the illumination very much more. Although somewhat expensive, the lighter varieties of Crookes's glass will be found the most generally useful for most purposes, and they are particularly efficient where the ultra-violet region of the spectrum is to be cut down as well as the visible rays. In those cases of disease where it is advisable that a minimum of light only should enter the eye, the most efficient glass is a *peacock blue*. It cuts off the infra-red and ultra-violet and a large proportion of the luminous rays as well, and although the luminosity, and therefore the visual acuity, is very much diminished, it has usually a most soothing effect psychologically upon such patients.

Sometimes it is advisable to exclude preferentially the *infra-red rays*. These are harmful to the eye, and when

Digitized by Illinois College of Optometry Library

absorbed in quantity may produce cataract and retinal lesions of the nature of burns. Sunlight contains a large quantity of these heat rays, but rarely enough to do harm unless the sun is looked at directly, when the lesions of eclipse blindness are produced. In tropical countries, however, it is wise to give some protection against them, and Crookes's glass is usually sufficient for this purpose. In some industries there is a considerable exposure to infra-red, as for example, in the smelting of metals and the making of glass; and in these a more efficient glass to employ, provided the conditions of work allow of its use, is *Crookes's sage-green glass*. This eliminates 95 per cent. of the infra-red as well as the ultra-violet and a proportion of the luminous spectrum.

The *ultra-violet rays* are not present in ordinary sunlight in sufficient intensity to give any trouble, except when they are reinforced by the reflection from snow or some extensive surface which acts as a mirror. In this case they give rise to the extremely painful condition of photophthalmia on account of their desquamating effect upon the cornea. In some industries, such as electric welding or in those where arc lamps are used, in cinema studios, and in ultra-violet light clinics, provision against short-waved light must also be made. The most efficient glass for this is Crookes's which cuts off the whole of the lower reaches of the spectrum, and which, if used in some of its darker shades, reduces the glare of the luminous light as well. Where it is desirable to cut off both ends of the spectrum and to tone down the luminous region to an extent which will allow efficient visual acuity for work, *Pfund's gold-plated glass* is very effective. This is made up of a very thin layer of prepared gold placed between a lens of ordinary crown glass and one of Crookes's A. The crown glass merely serves to protect the layer of gold; the layer of gold reflects 98 per cent. of the infra-red and allows 75 per cent. of the luminous waves to pass through; while the Crookes's glass cuts off

Digitized by Illinois College of Optometry Library

the ultra-violet. It thus forms an efficient all-round protective.

Glasses designed as a *protection against mechanical injury* are usually provided with side-pieces in the form of *goggles*, and are used in many industries. They may be either supplied as flat pieces of glass, or, in order to provide a greater visual field, they may be blown into the shape of a globe. In the latter case, however, the unequal cooling of the glass often gives rise to distortion effects.

To avoid the danger of splintering, *triplex glass* may be used in spectacles. They are especially useful for motorists and aviators, or for children, or those who play games

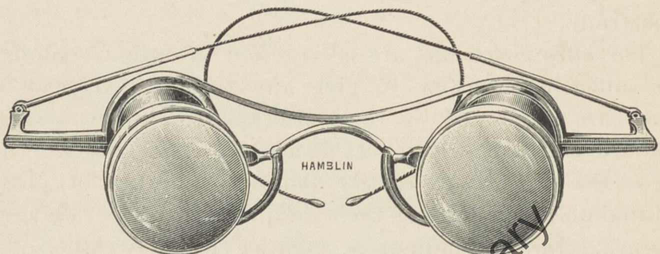


FIG. 204.—GALILEAN SPECTACLES.

wearing their glasses. The lens consists of two segments of glass between which is a plate of xylonite, the three being cemented together in a manner sufficiently adhesive that if the whole is shattered, it cracks into fragments but does not splinter and fly, while at the same time, it remains air- and water-tight. It can be ground into any lens form in the ordinary way. *Rowlite* is another more recently produced glass, which has the same properties. In it the interpolated material is itself adhesive, and consequently no sealing is required at the edges and the lens is considerably thinner.

Special Glasses for Optical Purposes.—Many different types of glasses have been designed for special purposes, most of which are ingenious and interesting. Divers, for example, who are virtually deprived of the refractive effect

Digitized by Illinois College of Optometry Library

of the cornea owing to their immersion in water, are provided with two meniscus lenses enclosing between them a bi-concave lens of air. From the general ophthalmological point of view, however, it is important to have a knowledge of those expedients which have been adopted to provide patients whose visual acuity is small with a useful amount of vision.

In those cases where disease of the retina is responsible for the visual failure, such as, for example, cases of retinitis and high myopia, a certain amount of vision can sometimes be obtained by the use of telescopic (or Galilean) spectacles (Fig. 204). In cases of myopia over — 25 D a

Fig. 205.—The Hydrodiascope of Siegrist.

single lens becomes impractable on account of the distortion effects to which it gives rise and the smallness of the image which it produces. Recourse may therefore be had to a combination of lenses arranged after the manner of an opera glass, or Galilean telescope, suitably adapted in size and design. The object glass is a convex lens which converges the incident rays, and the eye-piece, which is a concave lens placed within the focal length of the former, gives them the necessary divergence for distinct and magnified vision. A cylindrical correction can be incorporated, and fittings can be adjusted, to suit distant and near vision. Such a glass, however, although it is often the only alternative to virtual blindness, is cumbersome, weighty, and expensive, and suffers

Digitized by Illinois College of Optometry Library

from the defect of all magnifying optical instruments that it reduces the field of vision in proportion to the degree of magnification obtained.

A more homely and less efficient device, as far as near work is concerned, is to employ an ordinary magnifying glass held in the hand near the object of attention. This is merely

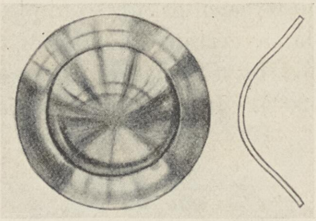


Fig. 206.—The Contact Glass of Sulzer.

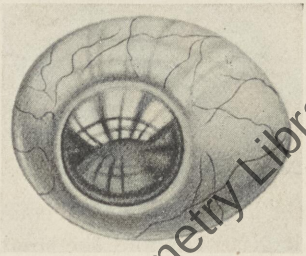


Fig. 207.—The Contact Glass of Müller.

a bi-convex lens, and the magnifying power which it provides is approximately one-quarter of its dioptric power: thus a + 16 D lens will magnify about × 4 diameters. The main trouble with such an expedient is the distortion of the image which is produced, a defect which can be diminished by using an aplanatic system of lenses such as is exemplified in the familiar ophthalmic loupe.

Where the fault in the eye takes the form of an extreme deformation of the corneal curvature, such as is seen in

Digitized by Illinois College of Optometry Library

conical cornea, it may be overcome by eliminating the effect of the cornea by substituting for it an artificial symmetrical one. A " hydrodiascope " has been suggested for this purpose by Lohnstein and Siegrist (Fig. 205) : it is a shallow metal cup filled with water, fitting closely to the orbital margin by a rubber rim and strapped round the head by an elastic band, provided with a suitably ground window of glass in front. A more suitable apparatus is the *contact glass* (Figs. 206 and 207). It is inserted under the eyelids and does not attract too much attention, while it can be worn for a considerable length of time without doing the corneal epithelium any ascertainable harm. The glass itself forms a suitable lens to replace the curve of the cornea, and

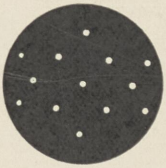


FIG. 208.—STENOPAEIC " GLASSES " (AFTER KNAPP).

with it the visual acuity in cases of conical cornea has been reported as being improved from 6/60 to 6/6.

Where the transparency of the cornea is at fault, a *stenopaeic hole* sometimes forms the only expedient by which any degree of useful vision may be obtained. It should, if possible, be placed opposite a transparent part of the cornea. Its optical properties have already been dealt with (see p. 77). As an emergency measure, it is sometimes useful. Its main disadvantage is that it provides no visual field, and since the eye cannot move behind it, it is of very little advantage to the wearer when walking about. It is useful, however, in reading, when it is best held in the hand following the line of print. When it is required for general purposes, a " glass " composed of several such openings bored in a sheet of opaque metal, as suggested by Knapp, may prove better than nothing (Fig. 208).

Digitized by Illinois College of Optometry Library

It is to be noted that the stenopaeic opening will prove equally useful in any error of refraction, and in the event of a pair of glasses being lost or broken, it will enable a presbyope, for example, to read or write in an emergency. It is interesting that its properties have long been made use of, usually in the form of a horizontal stenopaeic slit, by the primitive Eskimos, as a protective measure from the ultraviolet radiation reflected from the snow.

Digitized by Illinois College of Optometry Library

APPENDIX I

REFRACTIVE INDICES (FRAUNHAUFER LINE D)

Crown glass, fluor . .	1·4785
boro-silicate .	1·5087
hard . .	1·5155
zinc . . .	1·5149
barium—light .	1·5407
medium	1·5744
dense .	1·5881
Flint glass, extra light . .	1·5290
light barium .	1·5515
dense . . .	1·6182
extra dense .	1·6469

Digitized by Illinois College of Optometry Library

APPENDIX II

TABLE SHOWING THE EQUIVALENTS OF CENTRADS IN PRISM DIOPTRES, IN DEGREES OF DEVIATION, AND IN DEGREES OF THE REFRACTING ANGLE.

INDEX TO REFRACTION 1·54.

$m\Delta = \dfrac{\text{Tan } n^\circ \text{ dev.}}{0{\cdot}01}$ $\qquad 1\nabla = \dfrac{360^\circ \text{ dev.}}{200\pi} = 0{\cdot}57296^\circ\text{d.}$ $\qquad \text{Tan } \tfrac{1}{2} A^\circ = \dfrac{\text{Sin } \tfrac{1}{2} n^\circ \text{ dev.}}{1{\cdot}54 - \text{Cos } \tfrac{1}{2} n^\circ \text{ dev.}}$

Centrads	Prism Dioptres $= m^{\Delta}$	Deviation $= n^\circ$ dev.	Refracting Angle $= A^\circ$
1▽	1·0000△	0·57296°d	1·061°
2	2·00028	1·14592	2·123
3	3·00092	1·71888	3·181
4	4·00216	2·29184	4·240
5	5·0042	2·86480	5·298
6	6·00726	3·43776	6·351
7	7·01151	4·01072	7·407
8	8·01714	4·58368	8·458
9	9·02443	5·15664	9·506
10	10·03351	5·7296	10·551
11	11·04462	6·30256	11·593
12	12·05798	6·87552	12·631
13	13.07380	7·44848	13·665
14	14·09226	8·02144	14·694
15	15·11358	8·59440	15·719
16	16·13800	9·16736	16·740
17	17·16578	9·74032	17·75
18	18·19700	10·31328	18·76
19	19·23206	10·88624	19·76
20	20·27110	11·4592	20·72
25	25·53428	14·324	25·64
30	30·93375	17·1888	30·34
35	36·50300	20·0536	34·82
40	42·27951	22·9184	39·07
45	48·30571	25·7832	43·08
50	54·63050	28·648	46·83
60	68·33401	34·3776	53·63
70	84·22932	40·1072	59·44
80	102·96451	45·8368	64·35
90	126·01675	51·5664	68·44
100	155·74212	57·296	71·79

RELATIONSHIP BETWEEN REFRACTING ANGLE OF PRISMS AND THE AMOUNT OF DEVIATION PRODUCED.

Refracting Angle	Actual Deviation
1°	0·533°d
2	1·0833
3	1·633
4	2·167
5	2·7
6	3·25
7	3·8
8	4·33
9	4·88
10	5·43
11	5·97
12	6·533
13	7·083
14	7·63
15	8·2
16	8·765
17	9·317
18	9·884
19	10·45
20	11·033
25	13·95
30	16·98
35	20·167
40	23·567
45	27·216
50	31·533
52	32·93
54	34·716
56	36·6
58	38·6
60	40·7

Digitized by Illinois College of Optometry Library

APPENDIX III

METRE ANGLES (PERCIVAL, 1928)

The value of the unit metre angle depends on half the interocular distance (I.O.), which varies commonly from 56 to 64 mm.

Where m denotes half the interocular distance in mms., then 1 m.a. $= \sin^{-1}\left(\frac{m}{1000}\right)$. The following table gives the values in degrees and centrads for some interocular distances.

I.O.	56 mm.	58 mm.	60 mm.	62 mm.	64 mm.
1 m.a.	1° 36·27′ 2·8004 ▽	1° 39·71′ 2·9004 ▽	1° 43·15′ 3·0005 ▽	1° 46·59′ 3·1006 ▽	1° 50·03′ 3·2006 ▽

In the following table are given the values of some of the multiples of the metre angle which corresponds with an interocular distance of 60 mm.

M.A.	Degrees.	Centrads.	M.A.	Degrees.	Centrads.
1	1° 43·15′	3·000 ▽	9	15° 39·86′	27·339 ▽
2	3° 26·39′	6·004 ▽	10	17° 27·46′	30·469 ▽
3	5° 9·82′	9·012 ▽	11	19° 16·13′	33·630 ▽
4	6° 53·53′	12·029 ▽	12	21° 6·00′	36·827 ▽
5	8° 37·62′	15·057 ▽	13	22° 57·27′	40·063 ▽
6	10° 22·19′	18·099 ▽	14	24° 50·08′	43·345 ▽
7	12° 7·34′	21·157 ▽	15	26° 44·62′	46·677 ▽
8	13° 53·19′	24·237 ▽	16	28° 41·12′	50·065 ▽

Digitized by Illinois College of Optometry Library

APPENDIX IV.

LENSES OF SAME EFFECTIVITY FOR NEAR AND DISTANT WORK (Percival, 1928)

D_0 = lens for distance work.
D' = lens for near work (30 cm.).
${}_1D_0$ = equivalent lens placed in contact with the cornea (corneal contact lens).

Convex.			Concave.		
D_0 $p = \infty$	${}_1D_0$ $p = \infty$	D' $p = \cdot 3$	D_0 $p = \infty$	${}_1D_0$ $p = \infty$	D' $p = \cdot 3$
+ 1	+ 1·014	+ 1·092	− 1	− 0·987	− 1·093
+ 2	+ 2·056	+ 2·183	− 2	− 1·947	− 2·188
+ 3	+ 3·128	+ 3·272	− 3	− 2·882	− 3·284
+ 4	+ 4·230	+ 4·360	− 4	− 3·794	− 4·382
+ 5	+ 5·365	+ 5·447	− 5	− 4·682	− 5·481
+ 6	+ 6·533	+ 6·532	− 6	− 5·549	− 6·581
+ 7	+ 7·737	+ 7·616	− 7	− 6·392	− 7·682
+ 8	+ 8·877	+ 8·699	− 8	− 7·215	− 8·785
+ 10	+ 11·574	+ 10·860	− 10	− 8·803	− 10·995
+ 12	+ 14·340	+ 13·016	− 12	− 10·316	− 13·210
+ 14	+ 17·292	+ 15·167	− 14	− 11·761	− 15·431
+ 16	+ 20·450	+ 17·313	− 16	− 13·141	− 17·658
+ 18	+ 23·835	+ 19·453	− 18	− 14·460	− 19·890
+ 20	+ 27·473	+ 21·588	− 20	− 15·723	− 22·127

Digitized by Illinois College of Optometry Library

APPENDIX V

FORMULÆ FOR PERISCOPIC LENSES (Percival, 1928)

In the formation of these lenses no attention is paid to the images formed on the peripheral parts of the retina ; the aim is to make the area of a macular confusion circle less than that of a macular cone (the radius of which is 0·001 mm.) when the eye is turned 30° from the primary position to view an object through an eccentric part of the lens.

CONVEX PERISCOPIC LENSES.

Solid Angle of 60° ; $\mu = 1{\cdot}523$.

D	For distance.		For 30 cm.	
	Ant. surf.	Ocular surf.	Ant. surf.	Ocular surf.
+ 1	+ 7·449D	— 6·5 D	+ 4·977D	— 4·00D
+ 2	+ 8·417D	— 6·5 D	+ 6·206D	— 4·25D
+ 3	+ 9·371D	— 6·5 D	+ 7·175D	— 4·25D
+ 4	+ 10·560D	— 6·75D	+ 8·138D	— 4·25D
+ 5	+ 11·490D	— 6·75D	+ 9·088D	— 4·25D
+ 6	+ 12·641D	— 7·00D	+ 10·264D	— 4·50D
+ 7	+ 13·536D	— 7·00D	+ 11·421D	— 4·75D
+ 8	+ 14·413D	— 7·00D	+ 13·022D	— 5·50D
+ 9	+ 15·270D	— 7·00D	+ 13·668D	— 5·25D
+ 10	+ 16·105D	— 7·00D	+ 14·299D	— 5·00D
+ 11	+ 16·697D	— 6·75D	+ 15·140D	— 5·00D
+ 12	+ 17·488D	— 6·75D	+ 15·956D	— 5·00D
+ 13	+ 17·826D	— 6·25D	+ 16·532D	— 4·75D
+ 14	+ 18·152D	— 5·75D	+ 17·090D	— 4·50D

Digitized by Illinois College of Optometry Library

APPENDIX V—*continued.*

CONCAVE PERISCOPIC LENSES

− D	Distance.		Distance 30 cm.	
	Ant. surf.	Ocular surf.	Ant. surf.	Ocular surf.
— 1	+ 6·25D	— 7·25D	+ 4·25D	— 5·25D
— 2	+ 5·75D	— 7·75D	+ 3·75D	— 5·75D
— 3	+ 5·00D	— 8·00D	+ 3·25D	— 6·25D
— 4	+ 4·75D	— 8·75D	+ 2·50D	— 6·50D
— 5	+ 4·25D	— 9·25D	+ 2·00D	— 7·00D
— 6	+ 3·75D	— 9·75D	+ 1·50D	— 7·50D
— 7	+ 3·25D	— 10·25D	+ 1·00D	— 8·00D
— 8	+ 2·75D	— 11·75D	+ 0·50D	— 8·50D
— 9	+ 2·25D	— 11·25D	Plane	— 9·00D
— 10	+ 2·00D	— 12·00D	— 0·50D	— 9·50D
— 11	+ 1·50D	— 12·50D	— 1·00D	— 10·00D
— 12	+ 1·25D	— 13·25D	— 1·25D	— 10·75D
— 13	+ 1·00D	— 14·00D	— 1·75D	— 11·25D
— 14	+ 0·75D	— 14·75D	— 2·00D	— 12·00D
— 15	+ 0·50D	— 15·50D	— 2·00D	— 13·00D
— 16	+ 0·25D	— 16·25D	—	—
— 17	Plane	— 17·00D	—	—
— 20	Plane	— 20·00D	—	—

Digitized by Illinois College of Optometry Library

APPENDIX VI.

Official Visual Requirements.

1.—THE ROYAL NAVY

(*a*) *Commissions*

Blindness or defective vision, squint, imperfect perception of colours, fistula lacrimalis, or any chronic disease of the eyes or eyelids renders the candidate unfit. The visual tests are as follows, the tests for distant and near vision being Snellen's :—

	Near vision.	Far vision.	Colour vision.
Cadets for Dartmouth— On entry .	0·6 each eye without glasses.	$\frac{6}{6}$ each eye without glasses.	Perfect
On leaving .	0·6 without glasses.	$\frac{6}{6}$ $\frac{6}{12}$ without glasses.	Perfect
Special Entry Cadets— (including Conway, Worcester and Pangbourne Cadets.)	0·6 without glasses.	$\frac{6}{6}$ $\frac{6}{12}$ without glasses.	Perfect
Marines . .	Same as for special entry.	—	—
Engineering .	0·6 glasses not allowed.	$\frac{6}{9}$ $\frac{6}{12}$	—
All others . .	0·6 each without glasses.	Not less than $\frac{6}{60}$ corrected to $\frac{6}{6}$ each eye.	Normal
Mercantile Cadets— Deck . .	—	$\frac{6}{6}$ $\frac{6}{12}$ not allowed glasses.	Normal
Engine room .	—	$\frac{6}{12}$ $\frac{6}{18}$ not allowed glasses.	Normal

With regard to the lower standards, the defect must be due to a refractive error. A high degree of hypermetropia will dis-

Digitized by Illinois College of Optometry Library

qualify. The lower standards are accepted only on the understanding that these officers will undergo a further test of eyesight on the completion of their sub-lieutenant's examination at the schools, and a further examination if considered necessary on attaining the age of twenty-five.

(b) Recruits for the Royal Navy and the Royal Marines

1. For candidates for the Seaman Class (including Boys and Youths), Royal Marines (excluding Marine Bandsmen), Engine Room Artificers, Ordnance Artificers, Boy Artificers and Ship's Cooks, full normal vision is required, viz., $\frac{6}{6}$ each eye tested separately.

2. For candidates for Electrical Artificers, other Artisan Ratings (Shipwrights, Joiners, Blacksmiths, Plumbers, Painters, etc.), and Stokers, the vision must be $\frac{6}{9}$ each eye tested separately.

3. For Sick Berth Staff and Royal Marine Band Boys, $\frac{6}{12}$ each eye tested separately.

4. For all other ratings, including Writers, Victualling Assistants, Boy Writers, Victualling Boys, Officers' Stewards and Cooks, and Boy Servants, the vision must not be less than $\frac{6}{12}$ both eyes.

5. For all ratings, except Writers, Officers' Stewards and Cooks, or Royal Marine Bands, the colour sense must be normal.

6. Marine Bandsmen, Sick Berth Staff, Writers, Victualling ratings, and Officers' Stewards and Cooks are allowed to wear glasses, but defects of vision must only be due to errors of refraction, and must be capable of correction to $\frac{6}{6}$ Snellen by means of glasses, and the candidate must be able to read D. = 0·6 without the aid of glasses.

7. To determine the acuity of vision, Snellen's letter types are used, and the colour sense is determined by means of the Edridge Green Colour Perception Lantern ; if not available, by means of the bead test.

2.—CANDIDATES FOR COMMISSIONS IN THE REGULAR ARMY, MILITIA, AND TERRITORIAL ARMY (INCLUDING THE INDIAN ARMY).

The Army Test Types will be used for distant vision, without glasses at a distance of 20 feet, and for the test for near vision without glasses, at any distance selected by the candidate.

The minimum standards of acuteness of vision with which a candidate for a commission will be considered fit, are as follows :—

Standard I

	Right Eye	*Left Eye*
Distant vision.—	V = $\frac{6}{6}$.	V = $\frac{6}{6}$.
Near vision.—	Reads 0·6.	Reads 0·6.

Digitized by Illinois College of Optometry Library

Standard II

Better Eye

Distant vision.—V = $\frac{6}{6}$.
Near vision.—Reads 0·6.

Worse Eye

V without glasses = not below $\frac{6}{60}$; and after correction with glasses = not below $\frac{6}{24}$.
Reads 1.

Standard III

Better Eye

Distant vision.—V without glasses = not below $\frac{6}{60}$; and after correction with glasses = not below $\frac{6}{6}$.
Near vision.—reads 0·8.

Worse Eye

V without glasses = not below $\frac{6}{60}$; and after correction with glasses = not below $\frac{6}{12}$.
Reads 1.

Each eye must have a full field of vision as tested by hand movements.

Squint or any morbid condition of the eyes or of the lids of either eye liable to the risk of aggravation or recurrence, will cause the rejection of the candidate.

Each eye will be examined separately and the lids must be kept wide open during the test. The candidate will be required to read the tests in ordinary daylight.

Inability to distinguish the principal colours will not be regarded as a cause for rejection, but the fact will be noted in the proceedings and the candidate will be informed.

The degree of acuteness of vision of all candidates for commissions will be entered in the proceedings in the following manner :—

V.R. = ... ; with glasses =......... ; Reads..........
V.L. = ... ; with glasses =......... ; Reads..........

No relaxation of the standard of vision will be allowed.

These regulations apply to candidates for appointment to commissions in the Indian Army.

3.—CANDIDATES FOR COMMISSIONS IN THE ROYAL AIR FORCE

The examination for determining the acuity of vision will be conducted with well illuminated standard test types without glasses at a distance of 6 metres (or 20 feet). The standard of minimum acuteness of vision with which a candidate will be accepted is, for distant vision, $\frac{6}{6}$ with each eye.

When the candidate is *otherwise specially fit* the eye specialist may recommend acceptance where the visual acuity is equal to $\frac{6}{9}$ in each eye, provided that such vision is correctable by glasses to $\frac{6}{6}$ in each eye, and the conditions laid down in the following

Digitized by Illinois College of Optometry Library

sub-paragraphs are fulfilled, and such candidate may be passed by the president of the board as fit.

Hypermetropia of 2 D or more in either eye will disqualify.

Both eyes must have good fields of vision as tested by hand movements.

There must be good binocular fusion and balance of the eye muscles.

There must be normal colour vision according to the Board of Trade standards.

Disease of the eyes or lids or any other morbid condition liable to aggravation or recurrence will be a cause for rejection.

4.—MASTERS AND MATES IN THE MERCANTILE MARINE

Letter Test

Letter Test to be Passed First.—The first test which the candidate is required to undergo is the letter test, and until he has passed this test he must not be allowed to proceed further with the examination.

Apparatus Used.—The letter test to be used for all candidates is that conducted on Snellen's principle by means of sheets of letters.

Object of the Test.—The object of the letter test is to determine whether the candidate can reach a sufficient standard of visual acuteness, or, in other words, to find out whether his eyesight is good or bad.

Standard of Vision Required.—Every candidate for a first certificate of competency will be required to possess normal vision. With the exceptions indicated on next page (see paragraph *), every candidate for a second or higher certificate will be required to possess normal vision.

"Normal vision" is defined, for the purpose of these Regulations, as ability to read correctly nine of the twelve letters in the sixth line and eight of the fifteen letters in the seventh line of a test sheet placed in a good light at a distance of 16 feet from the eye.

The candidate will have the option of using either eye separately or both eyes together.

Spectacles not Allowed.—During the examination in the letter test candidates must not be allowed to use spectacles or glasses of any kind, or any other artificial aid to vision.

Method of Testing.—The test sheets shall be hung on the wall, in a good light, but not in direct sunlight, at a height of 5 or 6 feet from the ground. The candidate should be placed at a distance of exactly 16 feet from the sheets, and exactly opposite them. This distance should be carefully measured and should never in any circumstances be varied.

Digitized by Illinois College of Optometry Library

One of the sheets should then be exposed, and the candidate should be asked to read the letters on each sheet, beginning at the top and going downwards. Any mistakes which he makes should be carefully noted. If then it is found that he has read correctly at least nine letters in the sixth line and eight letters in the seventh line of a sheet, the candidate may be considered to have normal vision, and should be marked "passed" in the appropriate column of the form of application (Exn. 2 or Exn. 2A, as the case may be).

* *Lower Standard required in Certain Cases.*—Candidates who are in possession of certificates obtained before January 1st, 1914, may be regarded as passing the letter test if they can read correctly with both eyes at least five of the eight letters in the fifth line of a test sheet.

Lantern Test

Apparatus.—A special lantern and a mirror have been provided for this test. The lantern should be placed directly in front of the mirror, so that the front part of the lantern is exactly 10 feet from the mirror. Care should be taken that the lantern is properly placed, that is to say, the lights reflected in the mirror must show clearly when viewed from the position of the candidate on the left of the lantern. The examiner should always satisfy himself that these conditions are fulfilled before commencing the examination.

Darkness Adaptation.—It is essential that a candidate should be kept in a room which is either completely or partially darkened for at least a quarter of an hour before he is required to undergo this test.

Before the examination commences the examiner must satisfy himself that the room in which it is conducted is so darkened as to exclude all daylight.

Method of Testing.—The lantern supplied for the examination is so constructed as to allow one large or two small lights to be visible, and is fitted with 12 glasses of three colours—red, white and green. At the commencement of the examination the examiner should show to the candidate a series of lights through the large aperture, and should require him to name the colours as they appear to him. Care should be taken in showing the white light to emphasise the fact that this light is not a pure white. If a candidate makes a mistake of calling this light "red" a proper red light should be shown immediately after and the candidate's attention directed to the difference between the two.

After a series of lights through the large aperture has been shown, the examiner should make a complete circuit with the two small apertures, requiring the candidate to name the colours of each set of two lights from left to right. To prevent any

Digitized by Illinois College of Optometry Library

possibility of the order in which the lights are arranged from being learnt, the examiner should at least twice in each circuit go back a varying number of colours.

A record of any mistakes made with either the large aperture or the two smaller apertures should be kept on Form Exn. 17b in accordance with the instructions thereon.

Passing or Failure.—If a candidate with either the large aperture or the two smaller apertures of the lantern mistakes red for green or green for red, he should be considered to have "failed" in the lantern test.

If the only mistake made by the candidate with the lantern is to call the white light "red," and if after his attention has been specially directed to the difference between the two he makes no further mistake of this nature, he should be considered to have passed in the lantern test.

If a candidate makes any other mistake with the lantern, *i.e.*, if he calls white "red" repeatedly or red "white" at all, or confuses green and white, his case should be submitted to the Principal Examiner of Masters and Mates and he should be told that the decision as to whether he is passed or failed, or a further examination is necessary will be communicated to him in due course. Pending the receipt of the Principal Examiner's instructions such a candidate should only be allowed to proceed with the remainder of the examination for a Certificate of Competency on the express understanding that the latter examination will be cancelled in the event of failure in the sight tests.

5.—CANDIDATES FOR APPOINTMENTS IN THE CIVIL SERVICE

Any serious defect of vision. A moderate degree of ordinary short sight corrected by glasses would not as a rule be regarded as a disqualification, but candidates for certain situations as, *e.g.*, preventive man in the Department of Customs and Excise, are liable to disqualification for defective colour vision or any other defect of vision. Candidates for some other appointments of a special character would be rejected for colour-blindness, but for the Covenanted Civil Service of India and for ordinary Home Appointments it is not by itself a disqualification.

Candidates for the Civil Service Commissioners' certificate for posts in the Postal Service.

No fixed standards of vision are prescribed. Each case is judged on its merits after the medical examination which every candidate must pass as a condition of certification.

Loss of sight of one eye by mechanical injury. If the other eye is sound and sufficient and not likely to become affected, the question of fitness will be specially considered ; but for situations for which the rules lay down that "any serious defect of vision

Digitized by Illinois College of Optometry Library

will disqualify," loss of sight of one eye would usually be regarded as a bar to appointment.

6.—APPOINTMENTS UNDER THE GOVERNMENT OF INDIA

The Ecclesiastical, Education, Geological Survey, Agricultural, Indian Finance, Customs, Civil Veterinary, and other Departments not specially provided for in the following pages.

1. A candidate may be admitted into the Civil Services of the Government of India if ametropic in one or both eyes, provided that, with correcting lenses, the acuteness of vision be not less than $\frac{6}{9}$ in one eye and $\frac{6}{6}$ in the other; there being no morbid changes in the fundus of either eye.

2. Cases of myopia, however, with a posterior staphyloma, may be admitted into the service, provided the ametropia in either eye does not exceed 2·5 D, and no active morbid changes of choroid or retina be present.

3. A candidate who has a defect of vision arising from nebula of the cornea is disqualified if the sight of either eye be less than $\frac{6}{12}$; and in such a case the acuteness of vision in the better eye must equal $\frac{6}{6}$, with or without glasses.

4. Squint or any morbid condition, subject to the risk of aggravation or recurrence, in either eye, may cause the rejection of a candidate. The existence of imperfection of colour sense will be noted on the candidate's papers.

The Departments of Forest, Survey, Telegraph, Factories, and for various Artificers.*

1. If myopia in one or both eyes exists, a candidate may be passed, provided the ametropia does not exceed 2·5 D, and if with correcting glasses, not exceeding 2·5 D, the acuteness of vision in one eye equals $\frac{6}{9}$ and in the other $\frac{6}{6}$, there being normal range of accommodation with the glasses.

2. Myopic astigmatism does not disqualify a candidate for service, provided the lens or the combined spherical and cylindrical lenses required to correct the error of refraction do not exceed — 2·5 D; the acuteness of vision in one eye, when corrected, being equal to $\frac{6}{6}$, and in the other eye $\frac{6}{9}$, together with normal range of accommodation with the correcting glasses, there being no evidence of progressive disease in the choroid or retina.

3. A candidate having total hypermetropia not exceeding 4 D is not disqualified provided the sight in one eye (when under the influence of atropine) equals $\frac{6}{9}$ and in the other eye equals $\frac{6}{6}$, with + 4 D or any lower power.

* Artificers engaged in map and plan drawing may be considered separately, and this standard relaxed if it appears to be desirable.

4. Hypermetropic astigmatism does not disqualify a candidate for the service, provided the lens or combined lenses required to cover the error of refraction do not exceed 4 D, and that the sight of one eye equals $\frac{6}{9}$ and of the other $\frac{6}{6}$, with or without such lens or lenses.

5. A candidate having a defect of vision arising from nebula of the cornea is disqualified if the sight of one eye be less than $\frac{6}{12}$. In such a case the better eye must be emmetropic. Defects of vision arising from pathological or other changes in the deeper structures of either eye, which are not referred to in the above rules, may exclude a candidate for admission into the service.

6. Squint or any morbid condition, subject to the risk of aggravation or recurrence, in either eye, may cause the rejection of a candidate. The existence of imperfection of colour sense will be noted on the candidate's paper.

Public Works Department and Superior Establishments, Railway Department

1. If myopia in one or both eyes exists, a candidate may be passed, provided the ametropia does not exceed 3·5 D, and if, with correcting glasses not exceeding 3·5 D, the acuteness of vision in one eye equals $\frac{6}{9}$ and in the other $\frac{6}{6}$, there being normal range of accommodation with the glasses.

2. Myopic astigmatism does not disqualify a candidate, provided the lens, or the combined spherical and cylindrical lenses, required to correct the error or refraction, do not exceed 3·5 D; the acuteness of vision in one eye, when corrected, being equal to $\frac{6}{9}$ and in the other $\frac{6}{6}$, together with normal range of accommodation with the correcting glasses, there being no evidence of progressive disease in the choroid or retina.

3. A candidate having total hypermetropia not exceeding 4 D is not disqualified, provided the sight in one eye (when under the influence of atropine) equals $\frac{6}{9}$, and in the other eye equals $\frac{6}{6}$, with + 4 D glasses, or any lower power.

4. Hypermetropic astigmatism does not disqualify, provided the lens or combined lenses required to cover the error of refraction do not exceed 4 D, and that the sight of one eye equals $\frac{6}{9}$ and the other $\frac{6}{6}$, with or without such lens or lenses.

5. A candidate having a defect of vision arising from nebula of the cornea is disqualified if the sight of that eye be less than $\frac{6}{12}$. In such a case the better eye must be emmetropic. Defects of vision arising from pathological or other changes in the deeper structures of either eye, which are not referred to in these rules, may exclude a candidate.

6. Squint or any morbid condition, subject to the risk of aggravation or recurrence, in either eye, may cause the rejection of a candidate. Any imperfection of the colour sense is a disqualification for appointment to the Engineering Branch of the

Digitized by Illinois College of Optometry Library

Railway Department, or as Assistant Superintendent in the Traffic Department. In all other cases a note as to any imperfection of colour sense will be made on the candidate's papers.

The Indian Medical Service and the Police Department

1. Squint, or any morbid condition of the eyes or of the lids of either eye liable to the risk of aggravation or recurrence, will cause the rejection of the candidate.

2. The examination for determining the acuteness of vision includes two tests; one for distant, the other for near vision. The Army Test Types will be used for the test for distant vision, without glasses, except where otherwise stated below, at a distance of 20 feet; and Snellen's Optotypi for the test for near vision, without glasses, at any distance selected by the candidate. Each eye will be examined separately, and the lids must be kept wide open during the test. The candidate must be able to read the tests without hesitation in ordinary daylight.

3. A candidate possessing acuteness of vision, according to one of the standards herein laid down, will not be rejected on account of an error of refraction, provided that the error of refraction, in the following cases, does not exceed the limits mentioned, viz.: (*a*) in the case of *myopia*, that the error of refraction does not exceed 2·5 D; (*b*) that any correction for *astigmatism* does not exceed 2·5 D; and, in the case of myopic astigmatism, that the total error of refraction does not exceed 2·5 D.

4. Subject to the foregoing conditions, the standards of the minimum acuteness of vision with which a candidate will be accepted are as follows:—

Standard I

Right Eye	*Left Eye*
Distant vision.—V = $\frac{6}{6}$.	V = $\frac{6}{6}$.
Near vision.—Reads 0·6.	Reads 0·6.

Standard II

Better Eye	*Worse Eye*
Distant vision.—V = $\frac{6}{6}$.	V, without glasses = not below $\frac{6}{60}$; and after correction with glasses = not below $\frac{6}{24}$.
Near vision.—Reads 0·6.	Reads 1.

Standard III

Better Eye	*Worse Eye*
Distant vision.—V, without glasses = not below $\frac{6}{24}$; and after correction with glasses = not below $\frac{6}{6}$.	V, without glasses = not below $\frac{6}{24}$; and after correction with glasses = not below $\frac{6}{12}$.
Near vision.—Reads 0·8.	Reads 1.

Digitized by Illinois College of Optometry Library

N.B.—In all other respects candidates for these two branches of the service must come up to the standard of physical requirements laid down for candidates for commissions in the army.

THE INDIAN PILOT SERVICE, AND CANDIDATES FOR APPOINTMENTS AS GUARDS, ENGINE-DRIVERS, SIGNALMEN, AND POINTSMEN ON RAILWAYS.

1. A candidate is disqualified unless both eyes are emmetropic, his acuteness of vision and range of accommodation being perfect.

2. A candidate is disqualified by any imperfection of his colour sense.

3. Strabismus, or any defective action of the exterior muscles of the eyeball, disqualifies a candidate for these branches of service.

THE INDIAN MARINE SERVICE, INCLUDING ENGINEERS AND FIREMEN

1. A candidate is disqualified if he have an error of refraction in one or both eyes which is not neutralised by a concave or by a convex 1 D lens, or some lower power.

2. A candidate is disqualified by any imperfection of his colour sense.

3. Strabismus, or any defective action of the exterior muscles of the eyeball, disqualifies a candidate for this branch of service.

SPECIAL DUTY

Candidates for special duty under Government must possess such an amount of acuteness of vision as will, without hindrance, enable them to perform the work of their office for the period their appointment may last. In all cases of imperfection of colour sense a note will be made on the candidate's papers.

7.—PILOT SERVICE

1. A candidate shall be examined both as to his physical fitness and as to his acuteness of vision and colour perception.

2. The sight tests shall be carried out in accordance with the Board of Trade Regulations applying to examinations for certificates of competency in force for the time being.

3. A candidate must have no defect of sight, and must have full normal vision in both eyes, each eye being examined separately without the aid of spectacles.

4. A candidate shall be disqualified by any imperfection of his colour sense or by squint, or any defective action of the eye muscles or any disease of the eye.

5. A candidate must be also otherwise physically fit for the duties of a pilot.

Digitized by Illinois College of Optometry Library

8.—CANDIDATES FOR SCHOLARSHIPS AND TEACHERSHIPS UNDER LOCAL EDUCATION AUTHORITIES

The recommendations of the Council of British Ophthalmologists are as follows :—

Visual Acuity.—In all candidates for scholarships and teacherships visual acuity, with correcting glasses should not be less than $\frac{6}{9}$ in the better eye.

Myopia.—A child of eleven with less than two dioptres of myopia should be passed. A child of eleven with two or three dioptres of myopia in either eye should be passed on probation and re-examined every six months.

A child of eleven with three or more dioptres of myopia in the better eye should be rejected for scholarship training.

At the age of fifteen those with more than four dioptres of myopia in the better eye should be deemed unfit to train for the teaching profession.

Candidates for entry to training colleges, who are, as a rule, about eighteen years of age, if they have more than five dioptres of myopia in the better eye should be rejected.

Astigmatism.—Simple myopic astigmatism exceeding three dioptres in the better eye should be a cause of rejection of candidates both for scholarships and for training as teachers. In cases of compound myopic astigmatism, unless the myopia is stationary, astigmatism of even two dioptres may be a cause of rejection.

Cases of hypermetropic astigmatism should be rejected only if visual acuity, with correcting glasses, in the better eye is less than $\frac{6}{9}$.

Hypermetropia.—This defect should not be a cause of rejection unless vision, with correcting glasses, in the better eye is less than $\frac{6}{9}$.

Special Cases.—If there is only one eye, or if there is only one useful eye, the other being amblyopic from non-progressive disease, which in no way affects nor is likely to affect the good eye, the case should be judged on the condition of the good eye.

In the case of candidates for University and technical senior scholarships, or those intending to specialise as teachers of certain technical subjects, greater latitude may be allowed after consideration of special circumstances as to nature of work, condition of the candidate's eyes in other respects, etc.

9.—BOARD OF EDUCATION

Report on Eyesight of Candidates for Teacherships by Ophthalmic Surgeon approved by Board. Information is required on the following points :—

1. The nature and extent of the defect.
2. Whether it can be compensated by glasses so as to enable the candidate to perform the duties of a teacher satisfactorily.

Digitized by Illinois College of Optometry Library

3. Whether it is progressive.
4. Whether the existence of the defect is likely either :
   (*a*) To shorten the term of active service as a teacher, or
   (*b*) To interfere with the candidate's efficiency as a teacher.

10.—RAILWAY SERVANTS

Class A.—Drivers, Train motormen, Firemen and Engine-cleaners. On application to enter the service.

1. Form Vision Test.—$\frac{6}{6}$ each eye separately.

2. Colour Vision Test.—To pass the test by the Edridge-Green Colour Perception Lantern.

Re-examination :—

(*a*) After illness or accident considered likely to affect the sight, also, if considered desirable, after any alleged cases of mistaking signals.

(*b*) On promotion to Fireman, the standard required on re-examination being $\frac{6}{6}$ $\frac{6}{9}$, and $\frac{6}{6}$ together.

(*c*) On appointment as Driver, the standard required on re-examination being $\frac{6}{9}$ $\frac{6}{12}$, and $\frac{6}{9}$ together.

(*d*) Further re-examination will be made at 50, 55 and 60 years of age.

(*e*) If the examinee cannot pass under clause (*c*) but can reach $\frac{6}{12}$ $\frac{6}{18}$, and $\frac{6}{12}$ together, he must be re-examined every three years up to the age of 60.

(*f*) If an examinee fails to pass under clause (*e*) he shall be given practical tests by means of semaphore signals at 800 yards and 1,000 yards, by flags of the standard design at 400 and 500 yards, and by the usual colour vision test.

A man will be considered eligible for *shunting duties* who passes the signal test at 200 and 400 yards, and the flag test at 150 yards, and the usual colour vision test.

In all cases, when 60 years of age is reached and every two years thereafter, re-examination will take place, both in form and colour vision.

Other Grades in Class A.—On application to enter the service.

1. Form Vision.—$\frac{6}{6}$ each eye separately.

2. Colour Vision.—Test as above.

Re-examination. As for Drivers, except that in the Practical Test the distance for signals is 200 and 400 yards, and for flags 150 yards.

The use of Glasses is permitted in the case of Signalmen, Passenger Guards and Ticket Collectors undergoing re-examination.

Class B.—On application to enter the service.

1. Form Vision.—$\frac{6}{9}$ $\frac{6}{12}$, and $\frac{6}{9}$ together.

2. Colour Vision.—Test as above.

Digitized by Illinois College of Optometry Library

Class C.—On application to enter the service.

1. Form Vision.—$\frac{6}{18}$ each eye separately.
2. Colour Vision.—No test.

N.B.—The above regulations are subject to slight variations by individual Railway Companies.

11.—POLICE FORCE

There is no general standard of vision.

Constables of the Metropolitan Police Force

Form Vision.—$\frac{6}{6}$ each eye separately.

12.—METROPOLITAN POLICE REGULATIONS FOR DRIVERS OF MOTOR CABS CERTIFICATE OF VISION

I hereby certify that I have this day examined by Snellen's test type the vision of......................an applicant for a Licence to act as Driver of..................... with the following result :—

Acuity—R.E. without glasses......... L.E. without glasses..........
R.E. with glasses............ L.E. with glasses..............

Field of vision by hand test..............................

He has no squint, colour blindness, or other defect of vision which would affect his fitness to act as such driver.

He is.............. to act as driver of the before-mentioned class of public carriage.

Signature, etc.

Drivers of motor omnibuses, char-a-bancs and electrical tramway cars are not allowed optical aid to bring the vision up to the requisite standard.

13.—FORM OF CERTIFICATE FOR THE PURPOSES OF THE OLD AGE PENSIONS ACT, 1908, AND THE BLIND PERSONS ACT, 1920.

I have examined the eyes of....................who stated that he/she was a claimant to a pension under the Blind Persons Act, 1920, and I am of opinion that he/she is............* so blind as to be unable to perform any work for which eyesight is essential.

Signature.................................
Qualification.............................
Date ....

* Please insert the word " not " if you consider it necessary.

Digitized by Illinois College of Optometry Library

INDEX

Aberration, chromatic, 65
peripheral, 70
spherical, 67
Absorption, 21
by glasses, 373
Accommodation, 155
age variation, 180
amplitude of, 160
anisometropia in, 166
anomalies of, 187
asthenopia in, 90
astigmatism in, 165
availability of, 166
binocular, 177
card, 162
convergence, 175, 220
diminished, 187
emmetropia in, 162
excessive, 90, 187, 189
exercises of, 194
far point of, 160
ill-sustained, 188, 195
increased, 187
inequality of, 188, 196
inertia of, 188, 196
insufficiency of, 187, 192
measurement of, 161
mechanism of, 156
myopia in, 111, 165
near point of, 160
nervous diseases and, 150
paralysis of, 150, 188, 196
physical, 159
physiological, 159
range of, 160
relative, 174
spasm, 187, 191
tests for, 312
Achromatic lens, 66
Advancement of muscle for squint, 249
Alpha, angle, 69
in hypermetropia, 88
in myopia, 109
Amblyopia, 91, 139
congenital, 236
ex anopsia, 139, 236
Amblyoscope, 210, 245
testing with, 211
training with, 245
Ametropia, 72
Amplitude of accommodation, 160
of convergence, 169
Angle alpha, 69, 88, 109
gamma, 70, 88, 109
kappa, 70, 88, 109
metre, 169
of deviation, 27
of minimum deviation, 30
of primary deviation, 233
of refraction, 27, 29
of secondary deviation, 233
of squint, measurement of, 327
visual, 63, 256
Anisometropia, 73, 138
accommodation in, 166
treatment of, 146
vision in, 139
Antimetropia, 138
Aphakia, 76, 145
diagnosis of, 145
vision in, 147
Aplanatic lens, 68
Aspherical lenses, 350
Asthenopia, 10
accommodative, 90
anisometropia, in, 139
astigmatism in, 137
cyclophoria in, 223
esophoria in, 223
exophoria in, 223
heterophoria in, 223
hypermetropia in, 90
hyperphoria in, 223
myopia in, 111
presbyopia in, 183
Astigmatic beam, 46, 121
fan, 126

Digitized by Illinois College of Optometry Library

Astigmatic lenses, 45
  refraction, 46, 121
Astigmatism, 73, 119
  accommodation in, 165
  changes in, 150
  corneal, 119
  curvature, 119
  direct, 124
  dynamic, 120
  etiology of, 119
  hypermetropic, 74, 124
  index, 76, 120
  indirect, 124
  irregular, 75, 133
  lenticular, 120
  mixed, 74, 124
  myopic, 74, 124
  oblique, 75, 124, 130
  radial, 71
  regular, 45, 74, 122
  symptoms of, 124
  treatment of, 129
  vision in, 125
Asymmetrical lenses, 346
Atropine, 18, 203. *See* Cycloplegia.
Axial hypermetropia, 74, 79
  myopia, 74, 100
Axis, optical, 69
  principal, 36
  secondary, 37
  visual, 69

Bar reading, 247
Base curve of lens, 349
  surface of lens, 348
Bifocal lenses, 340
Binocular accommodation, 177
  fixation, test for, 318
  vision, 207
    in anisometropia, 138
Blepharitis, 11
Buphthalmus, 100
  refraction in, 151

Cardinal points, 53
Cataract, 12
  in myopia, 109
  myopia in, 99
Centrad, 30
Centre, curvature of, 35
  geometrical, 353
  optical, 37, 353
Centre, of rotation, 70
Centring of glasses, 262
Chorea and eyestrain, 14
Choroiditis and refractive changes, 153
Chromatic aberration, 65
  difference of magnification, 67
Ciliary muscle, failure of, 90
    spasm of, 90
    unequal contraction of, 120
Circles of diffusion, 47, 71
Clinical methods, 247
  summary of, 329
Cocaine, 205. *See* Cycloplegia.
Combining surface of lens, 348
Comma, 71
Concave lenses. *See* Lenses.
Concomitant strabismus. *See* heterotropia.
Confusion letters, 127
Conical cornea, 133
Conjugate foci, 39
  movements, 206
Conjunctivitis and refraction errors, 11
Contact glass, 137, 381
Convergence, 167, 168
  accommodation and, 172, 220
  amplitude of, 169
  determination of, 314
  excess, 220
  far point of, 169
  insufficiency, 218
  measurement of, 169
  near point of, 168
  negative, 169
  positive, 169
  range of, 169
  relative, 177
Convex lenses. *See* Lenses.
Cornea, astigmatism in, 119
  conical, 133
  diseases of, and refraction, 152
  index of refraction, 57
  nebulæ in, 137
  opacities in, 137
  plana, 81
  radius of curvature of, 57
  reflex of, 57, 135, 145
  refraction by, 56
  tattooing of, 136
Crescent, myopic, 107
Curvature, centre of, 35
  radius of, 35

Digitized by Illinois College of Optometry Library

Cyclophoria, 217, 221
essential, 222
exercises in, 225
operation in, 228
pseudo, 221
symptoms, 228
tests for, 322
treatment, 224
Cycloplegia, 17, 198
advantages of, 199
astigmatism in, 128
disadvantages of, 199
glaucoma in, 152
hypermetropia, in, 92
myopia, in, 114
retinoscopy, in, 301
Cycloplegics. *See* Cycloplegia.
Cylindrical lenses, 42
measurement of, 50
notation of, 50
refraction by, 42

Decentration, 68
in eye, 68
of lenses, 353
in presbyopia, 186
Detection of lenses, 49
Deviation, angle of, 27, 233
primary, 233
secondary, 233
tests for, 233
Diabetes, hypermetropia in, 154
myopia in, 99, 153
Diffraction, 64
Diffusion, circles of, 47, 71
Dioptre, 47
prism, 30
Diphtheria, accommodation in, 197
Diplopia, and heterophoria, 222
and heterotropia, 241
Disc, Placido's, 134
Discission of lens in myopia, 117
Disjunctive movements, 206
Displacement of lens, 74
Distance of lenses from eye, 368
Distortion of image, 71
by lenses, 370
Divergence excess, 218
Diver's glasses, 378
Double prism of Maddox, 322
Duane, accommodation, card of, 162
tables of, 180, 188
Duboisine, 205. *See* Cycloplegia.
Duochrome, the, 308
Dynamic astigmatism, 121
refraction, 161

Emmetropia, 72
accommodation in, 163
Encephalitis lethargica, 151
accommodation in, 197
Epilepsy and eye-strain, 14
Esophoria, 217, 220
exercises in, 224
operation in, 228
prisms in, 226
symptoms of, 222
treatment of, 223
Esotropia, 242
Euphthalmine, 205. *See* Cycloplegia.
Examination, ophthalmological, 251
ophthalmoscopic, 270
routine, 251
subjective, 265
with plane mirror, 273
Exercises for heterophoria, 224
Exophoria, 217, 218
exercises in, 224
operation in, 228
prisms in, 226
symptoms of, 222
treatment of, 223
Exotropia, 242
Extorsion, 221
Eye, refractive system of, 55
Eye-strain, 4
anisometropia, in, 139
asthenopia, and, 10
astigmatism, in, 127
blepharitis and, 11
cataract and, 12
chorea and, 14
conjunctivitis and, 11
cyclophoria and, 223
epilepsy and, 14
esophoria in, 223
exophoria in, 223
glaucoma and, 12
headaches in, 12
heterophoria in, 223
hypermetropia in, 90
hyperphoria in, 223
infections and, 11, 14
iritis and, 12
migraine and, 13

Digitized by Illinois College of Optometry Library

Eye-strain, myopia in, 111
neurasthenia and, 14
pain in, 11
presbyopia in, 183
styes in, 11
symptoms of, 5
gross errors in, 6
mechanism of, 7
ocular, 10
referred, 12
small errors in, 7
visual, 6, 9
tics in, 13
treatment of, 16
vaso-motor disturbances in, 14
visual defects in, 6, 9

Faculty, fusion. *See* Fusion Faculty.
False macula, 241
Fan, astigmatic, 126
Far point of accommodation, 109, 160
convergence, 169
Fatigue, retinal, 10
Fixation point, 69
axis, 69
Focal distance, 39
interval, 46, 122
length, 39
line, 44, 122
Focus, 37
conjugate, 39
principal, 39, 53
Fogging method of visual testing, 266
Form of lenses, 345
Frames, centring of, 262
trial, 260
Franklin lenses, 340
Fusion faculty, 209
development of, 209
investigation of, 210
power of, 213
training of, 245
supplement, 220

Galilean spectacles, 137, 379
Gamma, angle, 70
in hypermetropia, 88
in myopia, 110
Geneva lens measure, 364
Geometrical centre of lens, 353
Glass, contact, 381
Crookes's, 376
crown, 334
Fieuzal, 376
flint, 335
gold plated, 377
peacock blue, 376
rowlite, 378
smoke, 376
soft-lite, 374
soft-lite thin-lite, 374
triplex, 378
umbral, 374
Glasses. *See* Spectacles.
anisometropic, 142
contact, 137
Galilean, 137
stenopaeic, 137
telescopic, 137
Glaucoma, accommodation in, 197
cycloplegics in, 152, 201
refractive changes and, 12
in, 151
Goggles, 378
Gold plated glass, 377

Headaches and eye-strain, 12
Heterophoria, 214
ætiology, 215
detection of, 215
exercises in, 224
innervational, 215
muscular, 215
operations for, 228
prisms in, 226
symptoms of, 222
tests for, 216, 317, 319
treatment of, 223
varieties of, 217
Heterotropia, 231
ætiology, 236
binocular vision in, 239
heterophoria and, 237
operations in, 245
spectacles in, 243
tests for, 326
varieties of, 242
Homatropine, 204. *See* Cycloplegics.
"Hook-fronts," 344
Hydrodiascope, 137, 381
Hyoscine, 205. *See* Cycloplegics.
Hyoscyamine, 205. *See* Cycloplegics.

Digitized by Illinois College of Optometry Library

Hyperesophoria, 217
Hyperexophoria, 217
Hyperidrosis in refractive errors, 14
Hypermetropia, 73, 79
absolute, 84
accommodation in, 83, 164
acquired, 86
ætiology of, 79
age variation of, 85
angle alpha in, 88
axial, 74, 79
curvature, 74, 80
cycloplegics in, 91
facultative, 84
index, 75, 82
latent, 84
manifest, 84
optical condition in, 82
pathology of, 86
retinal appearances in, 87
symptoms of, 89
total, 84
treatment of, 91
Hyperopia. *See* Hypermetropia.
Hyperphoria, 217, 220
exercises in, 224
operations in, 228
prisms in, 226
symptoms of, 222
treatment of, 223
Hypertropia, 242
Hypometropia. *See* Myopia.

Image, 37
concave lens, with, 41
convex lens, with, 37
distortion of, 71, 371
in astigmatism, 125
ophthalmoscopy, in, 279
retinal, 62
in anisometropia, 140
in aphakia, 148
in hypermetropia, 83
in myopia, 110
size of, with glasses, 369
virtual, 39, 42
Index of refraction, 23
of cornea, 57
of lens, 59
Indirect ophthalmoscopy, 277
Infections and eye-strain, 14
Infra-red rays, protection from, 376
Intorsion, 221
Iridectomy, optical, 137
Iritis, accommodative spasm in, 191
myopia in, 191
refractive changes in, 151
errors and, 12
Irregular astigmatism, 133
treatment of, 136
types of, 133
Isochromatic glasses, 374

Jackson's crossed cylinders, 306
Jaeger's test-types, 267

Kappa, angle, 70
in hypermetropia, 88
in myopia, 109
Keratoconus, 75, 333
Kinetic strabismus, 236

Landolt's broken ring test, 264
Lens (crystalline), absence of. *See* Aphakia.
and accommodation, 157
astigmatism in, 120
capsule, and accommodation, 157
decentration of, 120
discission in myopia, 117
dislocation of, 151
displacement of, 74
dynamic astigmatism in, 121
obliquity of, 75
Lenses, 31
achromatic, 66
aplanatic, 68
astigmatic, 45
biconcave, 35
biconvex, 35
bifocal, 340
centring, 262
combinations of, 51
concave, 33
convex, 32
cylindrical, 42
decentring, 262
detection of, 49
foci of, 37, 41
images formed by, 37, 41
lock, 345
measure, 364,
measurement of, 49, 364
meniscus, 34, 68

Digitized by Illinois College of Optometry Library

Lenses, negative, 47
neutralisation of, 49
notation of, spherical, 47
cylindrical, 48
periscopic, 68
plano-concave, 35
plano-convex, 35
positive, 47
protractor for, 366
refraction by, 32
spectacle. *See* Spectacle Lenses.
spherical, 34
thick, 35, 368
thin, 35
Lenticonus, 75, 99, 136
Lenticular glasses, 350
Light, diffraction of, 64
protection from, 373
reflection of, 21
refraction of, 21
Line, pupillary, 70
Lister lamp, 271
mirror, 287
Lock, lens, 345
Lorgnettes, 186
Luxe glasses, 342

Macropsia, 192
Maddox double prism, 322
prism verger, 324
rod, 216, 319
tangent scale, 321
V-test, 306
wing test, 323
Magnifying glasses, 380
Manufacture of spectacles, 333
Measurement of lenses, 49, 364
prisms, 29
Metre angle, 169
Micropsia, 197
Migraine, 13
Mobility of eyes, tests for, 318
Monocle, 186, 339
Multifocal lenses, 344
Muscle balance. *See* Heterophoria.
Muscles, ocular, 234
Mydriatics. *See* Cycloplegia.
Myodioptre, 159
Myopia, 73, 98
accommodation in, 111, 165
ætiology of, 98
axial, 74, 100
curvature, 74, 98
Myopia, development of, 100
discission for, 117
eye-strain in, 111
far point in, 109
glasses for, 114
hygiene in, 116
importance of, 18
index, 75, 99
iritis in, 191
malignant, 105
near point in, 109
near work in, 18, 102
operative treatment, 117
pathology of, 105
prognosis, 112
progress of, 104
progressive, 105
prophylaxis, 112
retinal changes in, 106
simple, 104
strabismus in, 112
symptoms of, 110
theories of, 103
treatment of, 114
types of, 104
visual defects in, 110
Myopic schools, 117

Near point of accommodation, 160
of convergence, 168
of determination of, 313
vision, testing of, 268
Neurasthenia and eye-strain, 14
Neutralisation of lenses, 49
of prisms, 29
Nodal point, 34
of reduced eye, 61
Nose glasses, 336, 338
Notation of lenses, 47
of prisms, 29

Oblique astigmatism, 124, 130
resolution of, 131
Opacities on ocular media, 274
Operations and refractive changes, 152
for squint, 249
Ophthalmological examination, 250
Ophthalmometer, 57, 129, 303
Ophthalmoscope, 272
Ophthalmoscopic examination, 270

Digitized by Illinois College of Optometry Library

Ophthalmoscopy, direct, 283
  indirect, 277
Optical axis, 69
  centre, 37, 353
  defects of eye, 63
  density, 23
  systems, 51
Orthophoria, 207
Orthoptic treatment, 245
Orthoscopic lenses, 362

Pantoscopic glasses, 344
Parallax, 274
Peacock blue glass, 376
Perception, simultaneous, 210
Perimeter, and angle of squint, 329
Periscopic lenses, 68, 349
Pfund's gold plated glasses, 377
Photo-direction, 2
Photo-reception, 2
Pin-hole camera, 78
  test, 77, 255, 266
Placido's disc, 134
Plane mirror, ophthalmoscopic examination by, 273
  principal, 53
Plano lenses, 346
Point, fixation, 69
  nodal, 54
  principal, 53
Presbyopia, 179
  symptoms, 182
  treatment, 182
Pressure, and refractive changes, 152
Priestley Smith's tape, 328
Primary deviation, 233
  position of eyes, 207
Prince's rule, 161
Principal axis, 36
  focus, 39, 53
  plane, 53
  point, 53
Prism, 27
  adverse, 224
  convergence measurement by, 172
  detection of, 28
  dioptre, 30
  double, of Maddox, 322
  measurement of, 29
  nomenclature of, 29
  refraction by, 26
  relieving, 225
  rotating, 29
  verger, 324
Prismosphere, 356
Protective glasses, 373
Protractor, lens, 366
Pseudo-cyclophoria, 221
Pseudo-papillitis, 87
  size of, 76
Pupillary line, 70
Punctum proximum. *See* Near Point.
Punctum remotum. *See* Far Point.
Pupil, contraction of, 167

Radial astigmatism, 71
Radius of curvature, 35
    of cornea, 57
    of lens' capsule, 59
    of reduced eye, 61
Range of accommodation, 160
  of convergence, 169
Recession of muscles for squint, 249
Red reflex, 273
Reduced eye, 60
Referred symptoms of eye-strain, 12
Reflection, 21
Reflex of fundus, 273
Refraction, 21
  angle of, 27, 29
  by lenses, 31
    astigmatic, 45
    concave, 41
    convex, 37
    plate, 23
    prisms, 26
  changes in, 149
    in age, 149
    in choroiditis, 153
    in corneal disease, 152
    in diabetes, 153
    in dislocation of lens, 151
    in encephalitis, 151
    in glaucoma, 151
    in iritis, 151
    in scleritis, 153
    in trauma, 151
  dynamic, 161
  estimation of, 286
    by ophthalmoscopy, 284
    by retinoscopy, 287
    subjective, 265
    verification of, 305
  index of, 23
  static, 161
Refractive system of eye, 55

Digitized by Illinois College of Optometry Library

Relative accommodation, 174
convergence, 177
Resolving power of eye, 63
Retinal changes in hypermetropia, 87
in myopia, 106
detachment in myopia, 108
fatigue, 10
image, formation of, 62
size of, 369
Retinoscopy, 286
mirror, 287
practice of, 293
theory of, 287
verification of, 305
Reversible glasses, 344
Rotating prisms, 29
Rotation, centre of, 70
Routine examination, 251
Rowlite glass, 378

Scheiner's experiment, 162
Schematic eye, 60
Scholar's spectacles, 337
School, conditions of, 18, 102, 113, 117
myopic, 117
Scleritis, and refractive changes, 153
Scopolamine, 205 *See also* Cycloplegia,
Screen test, 216
Secondary axis, 37
deviation, 233
position of eyes, 207
Segment of bifocals, 342
Shape of lenses, 345
Shooting glasses, 361
Shot-silk retina, 87
Simultaneous perception, 210
Size of lenses, 345
retinal image, 369
Smoke glasses, 376
Soft-lite glasses, 374
thin-lite glasses, 374
Spasm of accommodation, 187, 191
Spectacle frames, 335
fitting of, 336
tilted, 361
Spectacle lenses, 334
aspherical, 350
asymmetrical, 346
base curve of, 349
bifocal, 340
Spectacle lenses, centring of, 353
combinations of, 340
Crookes's, 376
decentring of, 353
Fieuzal, 376
form of, 345
isochromatic, 374
lenticular, 350
manufacture of, 335
meniscus, 347
multifocal, 340
orthoscopic, 362
pantoscopic, 344
periscopic, 349
plano, 346
reversible, 344
shape of, 345
size of, 345
smoke, 376
soft-lite, 374
symmetrical, 346
tinted, 373
toric, 349
transposition, 350
trifocal, 340
verification of, 363. *See also* Spectacles.
Spectacles, 332
discomforts of, 370
distortion by, 371
Galilean, 379
history of, 332
isochromatic, 374
manufacture of, 333
presbyopia in, 153
prescription of, 19, 311, 314
primitive, 333
protective, 373
reversible, 344
scholar's, 337
shooting, 361
sports, 361
telescopic, 379
tilted, 361, 367
tinted, 373
types of, 372. *See also* Spectacle Lenses.
Spherical aberration, 67
lenses, 35
Sports glasses, 361
Squint. *See* Strabismus.
Staphyloma posterior, 107
Static refraction, 161
Stenopaeic aperture, 76

Digitized by Illinois College of Optometry Library

Stenopaeic " glasses," 381
slit in irregular astigmatism, 136
Stereoscopic vision, 210
development of, 209
investigation of, 211
training of, 245
Strabismus, 230
alternating, 242
apparent. *See* Heterotropia.
concomitant. *See* Heterotropia.
constant, 242
dorsumvergens, 242
kinetic, 236
latent. *See* Heterophoria.
paralytic, 231
diagnosis, 233
symptoms, 234
treatment, 235
periodic, 242
sursumvergens, 242
unilateral, 242
Sturm's conoid, 46, 121
Subjective examination, 265
Sursumvergence, 213
Symmetrical lenses, 346
Symptoms of eye-strain, 5
Synkineses, 167

Tangent scale, 321
Tattooing of cornea, 136
Telescopic spectacles, 137, 379
Tenotomy for squint, 249
Test-types, Jaeger's, 267
Landolt's, 264
Snellen's, 256
Thick lenses, errors of, 368
Tics, and refractive errors, 13
Tilted glasses, 361, 367
Tinted glasses, 373
Toric lenses, 349
Transposition of lenses, 350
Trauma, and refractive changes, 151
Trial frames, 260, 370
lenses, 370
Trifocal glasses, 343
Triplex glass, 378
Types, Jaeger's, 267
Landolt's, 264
Snellen's, 256

Ultra-violet rays, protection from, 371
Umbral glass, 374

Vaso-motor disturbances in eye-strain, 14
Vergence, 213
Verging power, 213
test for, 324
Verification of glasses, 363
Virtual image, 39, 42
Vision, 1
alternating, 139
binocular, 210
in anisometropia, 138
primitive, 1
stereoscopic, 210
development of, 209
investigation of, 211
training of, 245
Visual acuity, 255
angle, 63, 256
axis, 69
symptoms of eye-strain, 9
Vitreous opacities in myopia, 107
V-test for astigmatism, 307

Weiss's streak, 107
Wing test of Maddox, 323
Worth's ivory ball test, 243, 265

PRINTED IN GREAT BRITAIN BY THE WHITEFRIARS PRESS, LTD.,
LONDON AND TONBRIDGE.

Digitized by Illinois College of Optometry Library

Digitized by Illinois College of Optometry Library

Digitized by Illinois College of Optometry Library

108496

RE925
.D9
1928
c.1

10.87

DEMCO

Digitized by Illinois College of Optometry Library

Digitized by Illinois College of Optometry Library